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BUILDING ROCKETS

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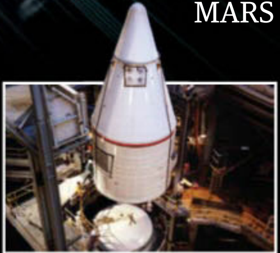

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Discover the wonders of the universe

Dark matter has been a mystery to us for over 40 years. It plays the role of a largely unknown substance that we cannot see, accounting for over 80 per cent of the matter in the universe. Ordinary matter on the other hand - that's me, you and everything that's visible to the human eye - takes up a shockingly small 15 per cent. Bring dark energy into the equation, and your ordinary matter is an even smaller 4.9 per cent. Dark energy is the force that is causing the expansion of the universe to accelerate, but is there enough dark matter to produce a gravitational pull to slow this expansion and prevent a 'Big Rip'? We find out who is on course to win this tug of war on page 16.

The universe is full of mysteries like dark matter. Another question is, does intelligent life exist on planets around other stars? This is the quest of the Search for Extra-Terrestrial Intelligence, or SETI, and it has recently received the boost of an extra $100 million (£65 million) to support the hunt over the next ten years. Will this be money well spent? We find out on page 60.

While the existence of intelligent life remains a mystery, closer to home two recent discoveries have increased the chances of finding simple life in our own Solar System. The presence of a global ocean underneath the icy crust of Saturn's moon Enceladus led **All About Space** to catch up with the Cassini mission's Carolyn Porco to find out more and, just as this issue was going to print, NASA announced that scientists have found evidence for running water on the surface of Mars, raising the possibility that life could exist on the Red Planet for a future mission to discover. You can find out more about this exciting new development on page 12.

Enjoy the issue - we did!

Gemma Lavender
Features Editor

> "We've had decades to think about dark matter, so there are lots of ideas on what it is"
> **Richard Massey, cosmologist, Durham University, UK**

Crew roster

David Crookes

■ David chats to the experts shedding light on the elusive dark matter. Find out what he discovered on page 16.

Laura Mears

■ Ever heard of zombie stars? Head over to page 48 for Laura's pick of space's most terrifying objects.

Jonny O'Callaghan

■ A new project to find out if we're alone in the universe will soon be underway. Jonny has the details on page 60.

Peter Grego

■ Seasoned astronomer Peter presents his guide to getting started in astronomy over on page 74.

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CONTENTS

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LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE

06 A stunning aurora, Mars rover selfie and mountains on the surface of Pluto feature in this month's Amazing Images.

FEATURES

16 **Dark matter**
All About Space sheds light on the secret controlling the universe

26 **Explorer's Guide to Venus**
Take a tour of the most hostile planet in the Solar System

30 **How to build a rocket**
Go behind the scenes with NASA, ESA and SpaceX to find out how it's done

38 **Interview Enceladus's global ocean**
We chat to NASA's Carolyn Porco about the vast expanse of water that's recently been confirmed on Saturn's moon

42 **Focus On LISA Pathfinder**
With less than two months until launch, we catch up with the gravitational-wave hunter

45 **5 amazing facts Magnetars**
Discover how these magnetic stars can wipe all the credit cards in the world

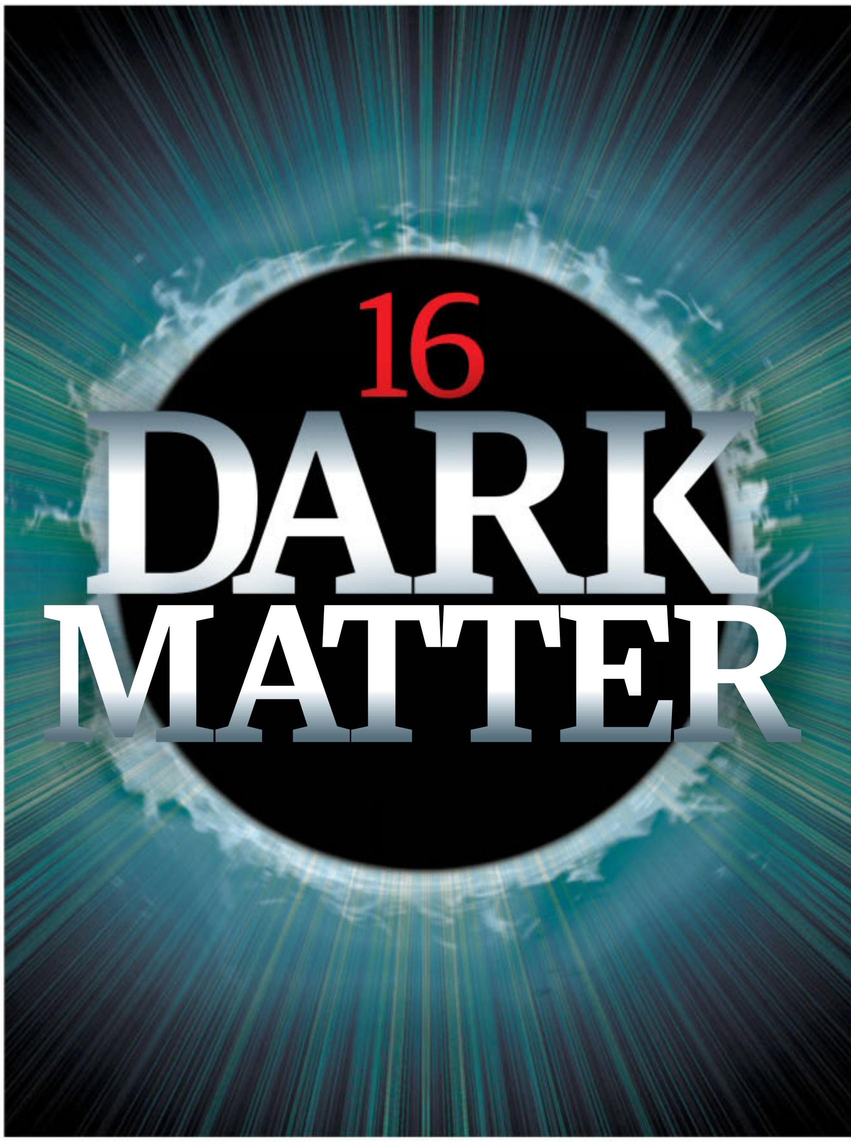
46 **Why is Mars so popular?**
Find out why we send so many missions to the Red Planet

48 **Zombie stars +10 other terrifying space objects**
The scariest stars, planets and galaxies that lurk in the corners of the cosmos

56 **Future Tech Space balloon tourism**
A voyage to the edge of space could be made a reality with World View

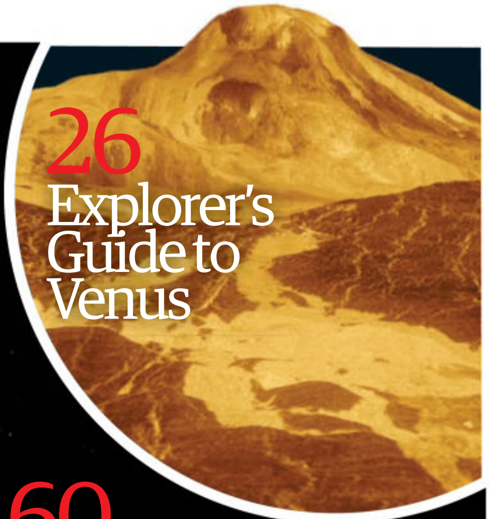
60 **New search for alien life**
A $100 million project could make or break the hunt for intelligent life

95 **WIN! A TELESCOPE WORTH £250**

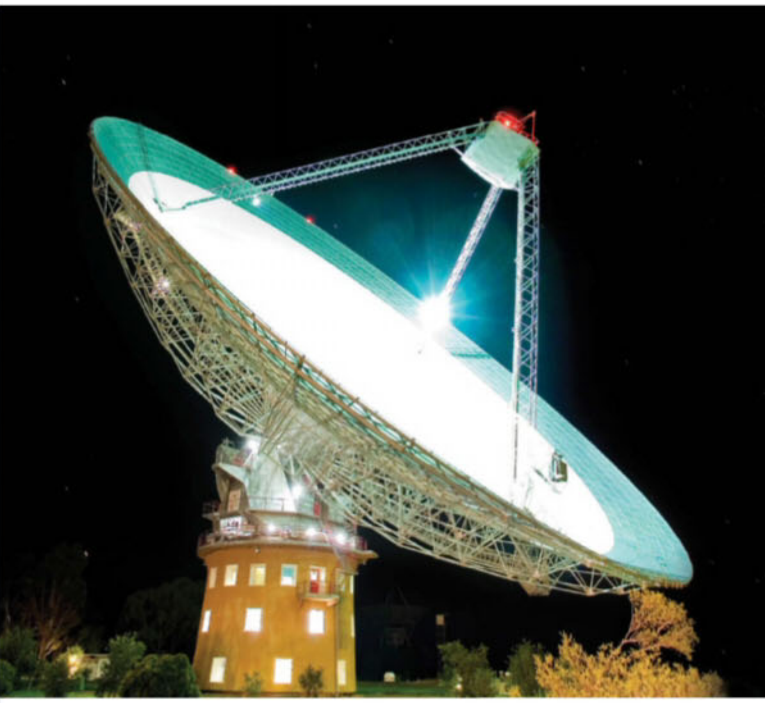


"Any living organisms on Enceladus may have had longer to evolve. Instead of micro-organisms, we may find lobster and sushi!"

38 Carolyn Porco, NASA

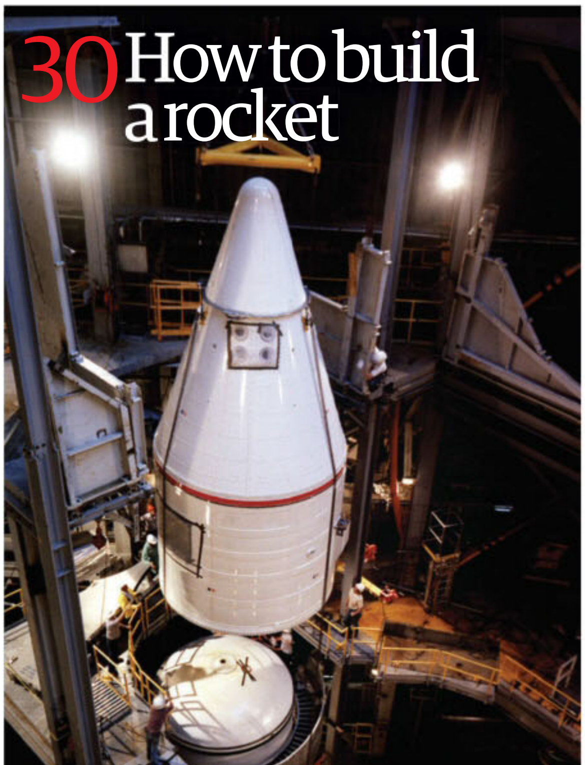


26 Explorer's Guide to Venus



60 New search for alien life

74 Become an astronomer (Part 1)



30 How to build a rocket

Space ANSWERS

68 **Your questions answered**
Our experts solve your space conundrums

STARGAZER

Top tips and astronomy advice for beginners

74 **Become an astronomer (Part 1)**
Start off on the right foot with part one of our essential astronomy guide

84 **How to view Comet Catalina**
Get the best views of a potential comet of the year

86 **What's in the sky?**
Our pick of the must-see night-sky sights this October

88 **Me & my telescope**
We feature more of your astrophotos and stargazing stories this month

92 **Telescope review**
We put a telescope made for the entire family to the test

96 **Astronomy kit reviews**
Vital kit for astronomers and space fans

98 Heroes of Space
John Grunsfeld, keeper of the Hubble Space Telescope

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Page 58

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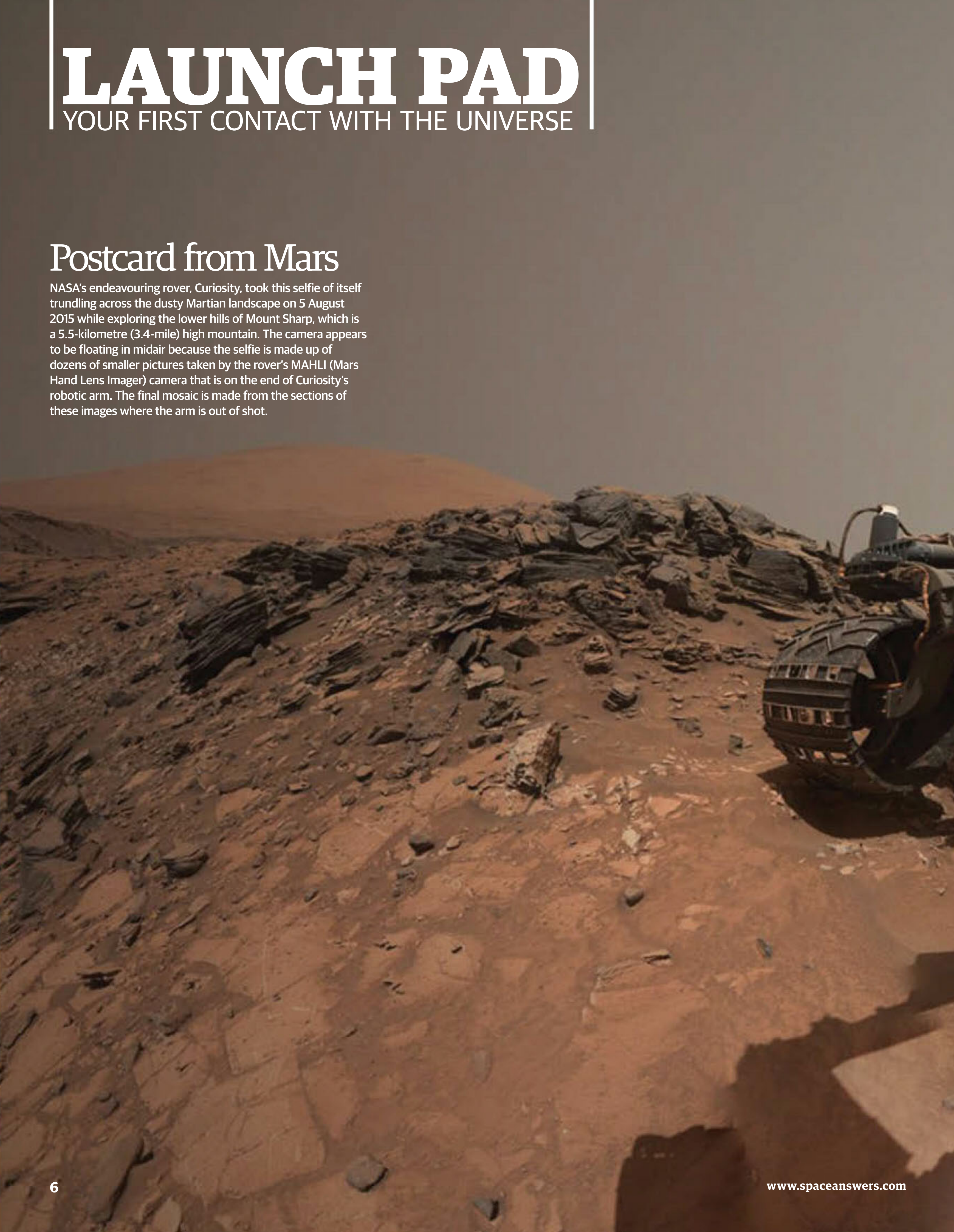
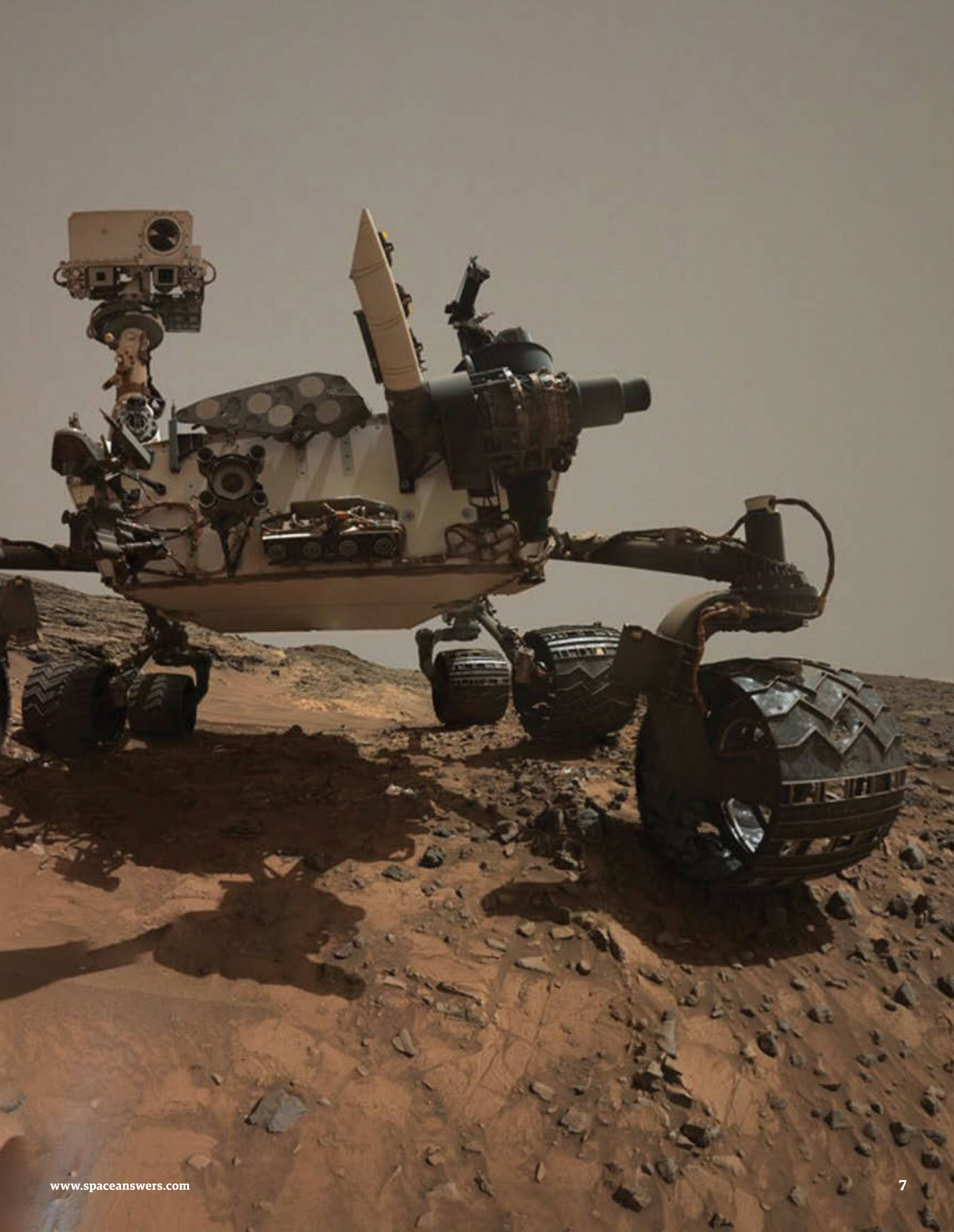
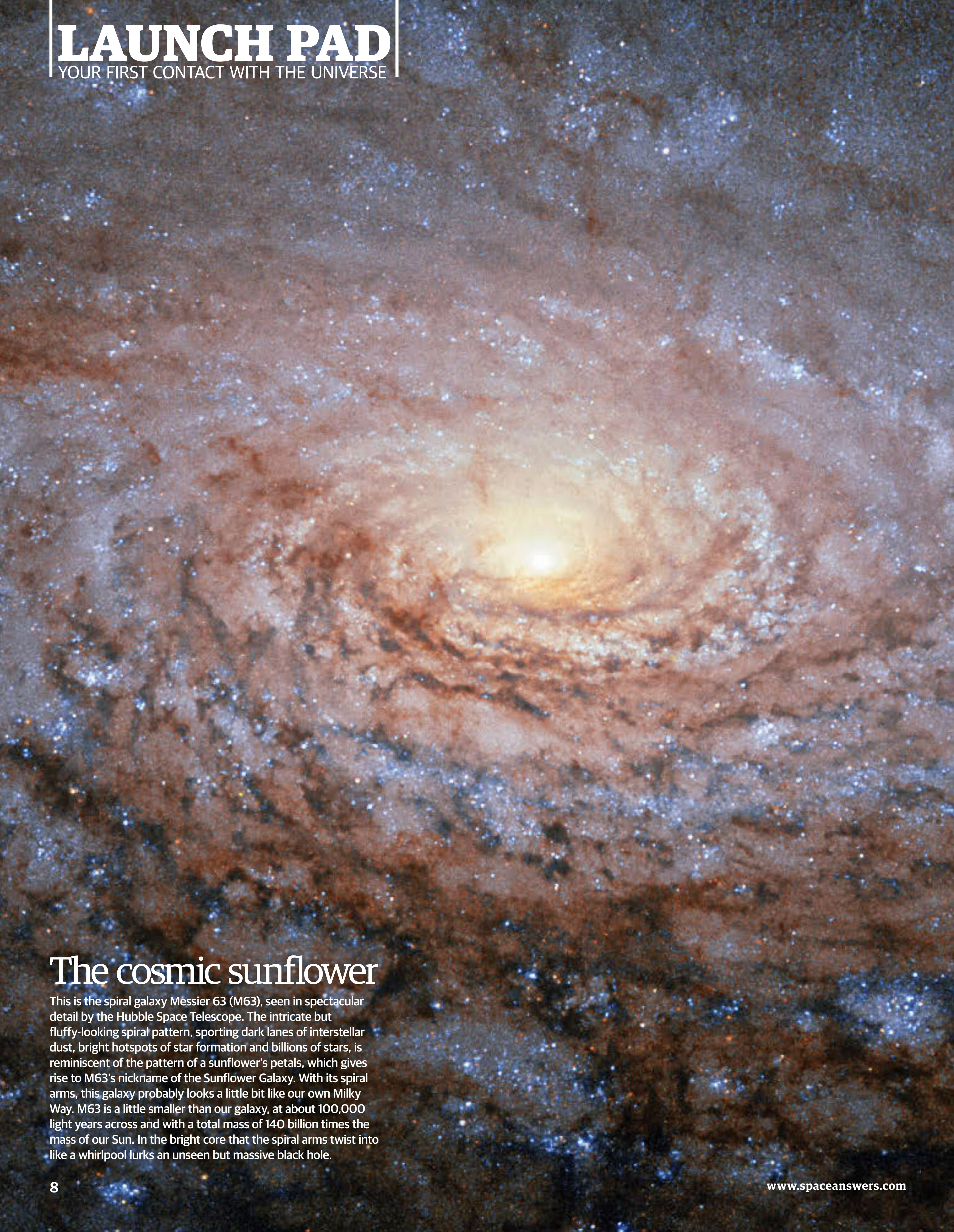


Postcard from Mars

NASA's endeavouring rover, Curiosity, took this selfie of itself trundling across the dusty Martian landscape on 5 August 2015 while exploring the lower hills of Mount Sharp, which is a 5.5-kilometre (3.4-mile) high mountain. The camera appears to be floating in midair because the selfie is made up of dozens of smaller pictures taken by the rover's MAHLI (Mars Hand Lens Imager) camera that is on the end of Curiosity's robotic arm. The final mosaic is made from the sections of these images where the arm is out of shot.



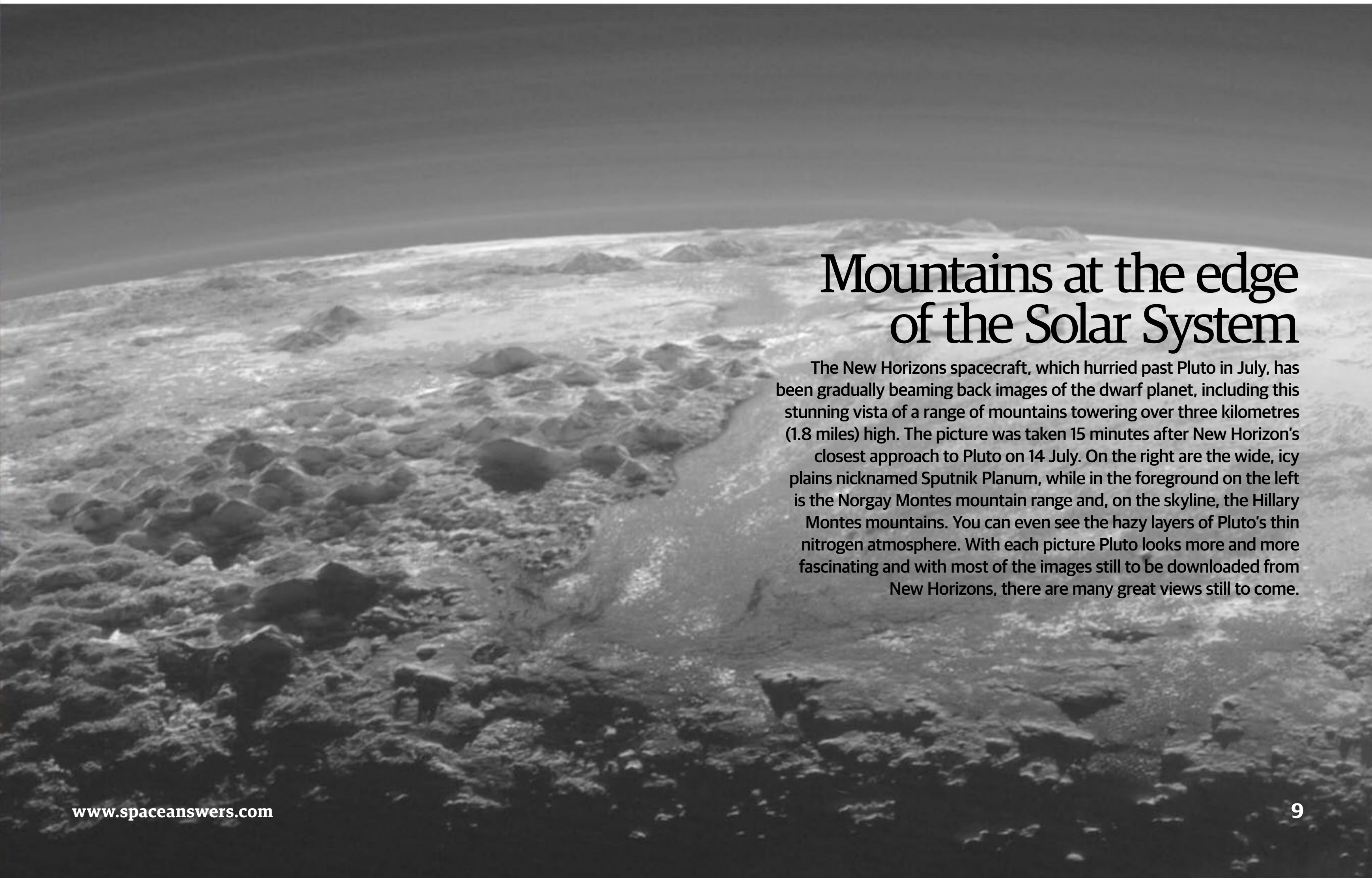


The cosmic sunflower

This is the spiral galaxy Messier 63 (M63), seen in spectacular detail by the Hubble Space Telescope. The intricate but fluffy-looking spiral pattern, sporting dark lanes of interstellar dust, bright hotspots of star formation and billions of stars, is reminiscent of the pattern of a sunflower's petals, which gives rise to M63's nickname of the Sunflower Galaxy. With its spiral arms, this galaxy probably looks a little bit like our own Milky Way. M63 is a little smaller than our galaxy, at about 100,000 light years across and with a total mass of 140 billion times the mass of our Sun. In the bright core that the spiral arms twist into like a whirlpool lurks an unseen but massive black hole.

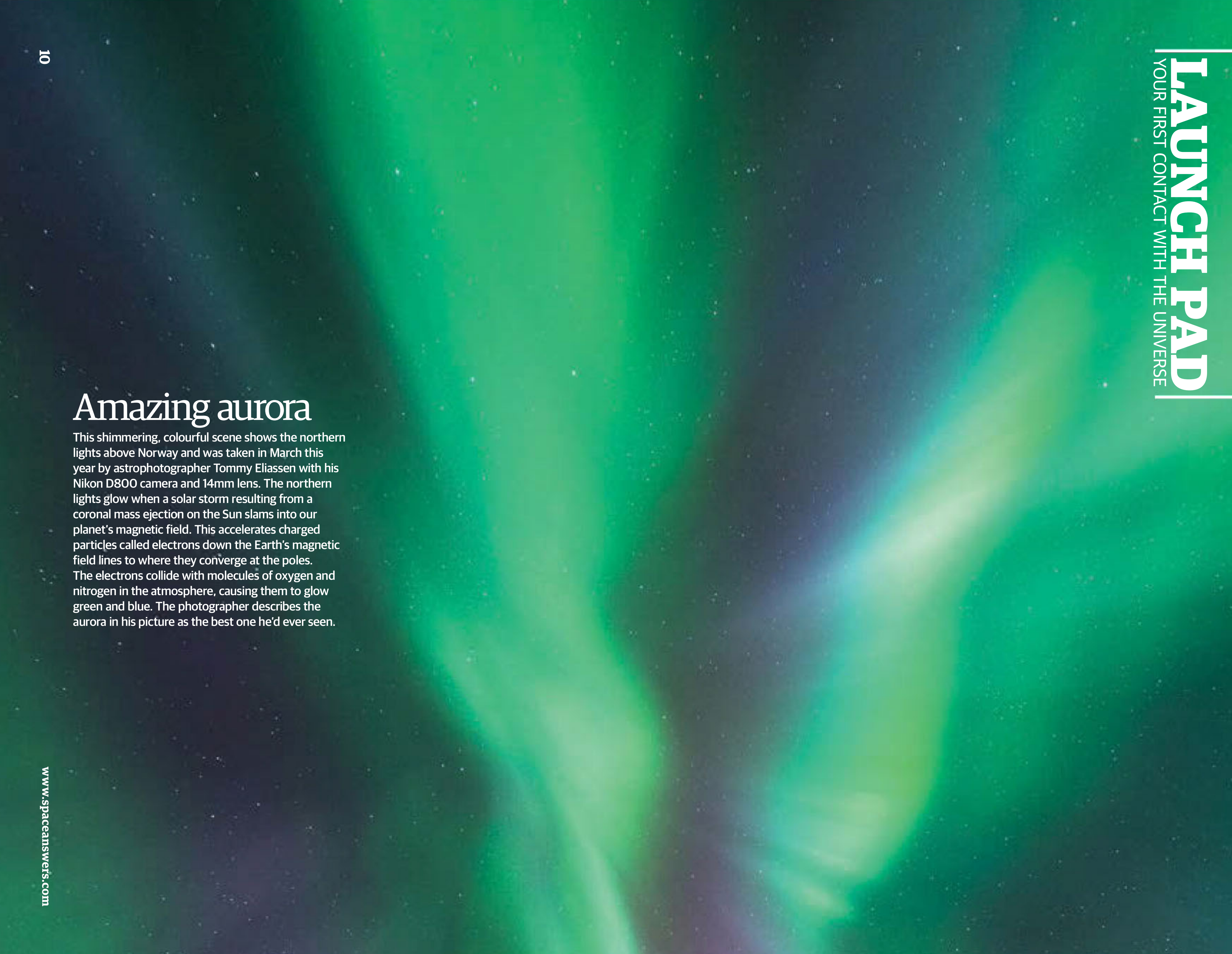
A fruitful mission

Not all space food is freeze-dried! The most recent cargo supply run to the International Space Station by the Japanese HTV-5 transfer vehicle, on 25 August 2015, delighted NASA astronaut Kjell Lindgren by bringing with it a bag of fresh fruit. The fruit spilled out under the microgravity of Earth orbit, no doubt leading to antics as the crew of the station then had to chase after the oranges and apples to gather them up.



Mountains at the edge of the Solar System

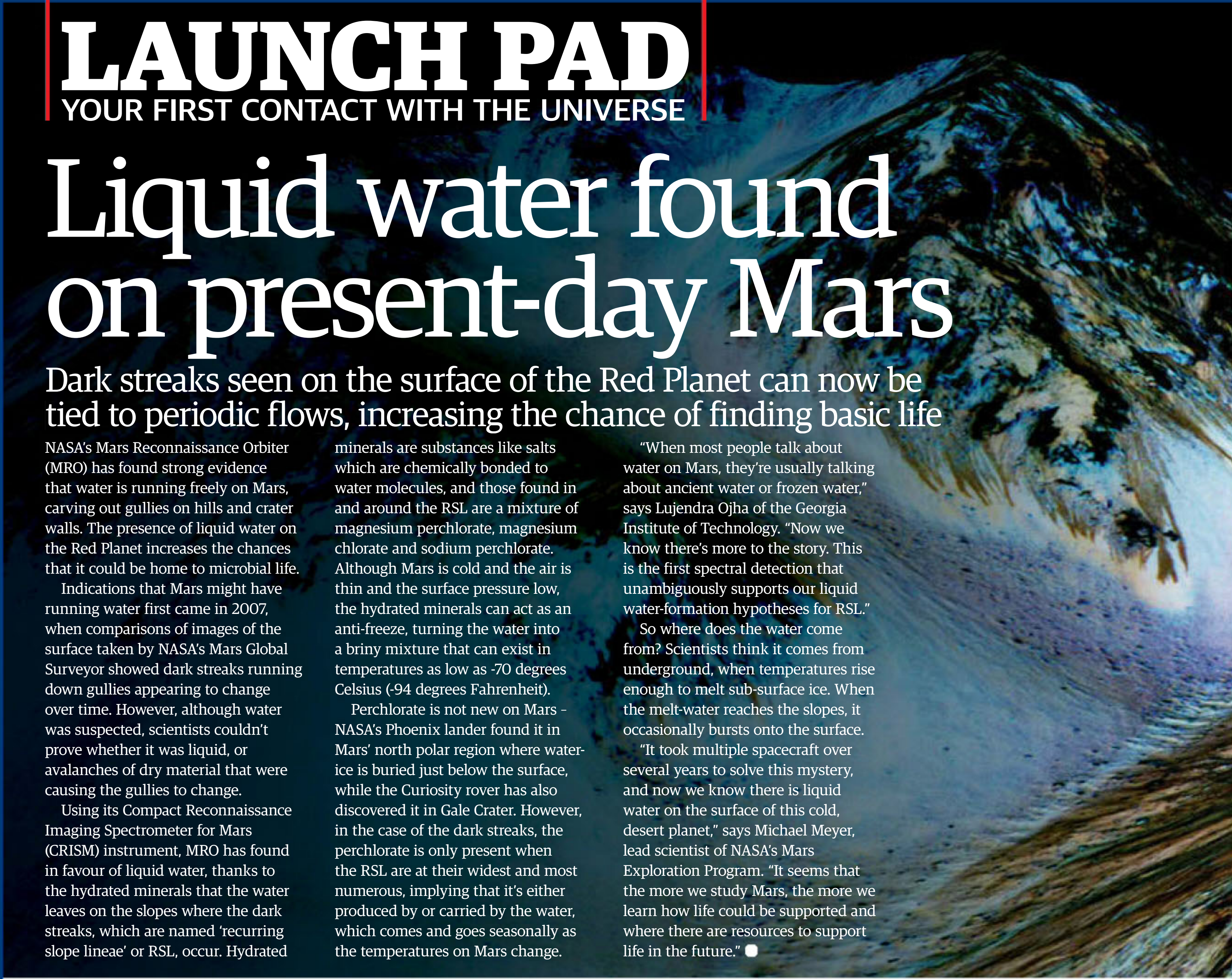
The New Horizons spacecraft, which hurried past Pluto in July, has been gradually beaming back images of the dwarf planet, including this stunning vista of a range of mountains towering over three kilometres (1.8 miles) high. The picture was taken 15 minutes after New Horizon's closest approach to Pluto on 14 July. On the right are the wide, icy plains nicknamed Sputnik Planum, while in the foreground on the left is the Norgay Montes mountain range and, on the skyline, the Hillary Montes mountains. You can even see the hazy layers of Pluto's thin nitrogen atmosphere. With each picture Pluto looks more and more fascinating and with most of the images still to be downloaded from New Horizons, there are many great views still to come.



Amazing aurora

This shimmering, colourful scene shows the northern lights above Norway and was taken in March this year by astrophotographer Tommy Eliassen with his Nikon D800 camera and 14mm lens. The northern lights glow when a solar storm resulting from a coronal mass ejection on the Sun slams into our planet's magnetic field. This accelerates charged particles called electrons down the Earth's magnetic field lines to where they converge at the poles. The electrons collide with molecules of oxygen and nitrogen in the atmosphere, causing them to glow green and blue. The photographer describes the aurora in his picture as the best one he'd ever seen.

© NASA; Tommy Eliassen



Liquid water found on present-day Mars

Dark streaks seen on the surface of the Red Planet can now be tied to periodic flows, increasing the chance of finding basic life

NASA's Mars Reconnaissance Orbiter (MRO) has found strong evidence that water is running freely on Mars, carving out gullies on hills and crater walls. The presence of liquid water on the Red Planet increases the chances that it could be home to microbial life.

Indications that Mars might have running water first came in 2007, when comparisons of images of the surface taken by NASA's Mars Global Surveyor showed dark streaks running down gullies appearing to change over time. However, although water was suspected, scientists couldn't prove whether it was liquid, or avalanches of dry material that were causing the gullies to change.

Using its Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument, MRO has found in favour of liquid water, thanks to the hydrated minerals that the water leaves on the slopes where the dark streaks, which are named 'recurring slope lineae' or RSL, occur. Hydrated minerals are substances like salts which are chemically bonded to water molecules, and those found in and around the RSL are a mixture of magnesium perchlorate, magnesium chlorate and sodium perchlorate. Although Mars is cold and the air is thin and the surface pressure low, the hydrated minerals can act as an anti-freeze, turning the water into a briny mixture that can exist in temperatures as low as -70 degrees Celsius (-94 degrees Fahrenheit).

Perchlorate is not new on Mars – NASA's Phoenix lander found it in Mars' north polar region where water-ice is buried just below the surface, while the Curiosity rover has also discovered it in Gale Crater. However, in the case of the dark streaks, the perchlorate is only present when the RSL are at their widest and most numerous, implying that it's either produced by or carried by the water, which comes and goes seasonally as the temperatures on Mars change.

"When most people talk about water on Mars, they're usually talking about ancient water or frozen water," says Lujendra Ojha of the Georgia Institute of Technology. "Now we know there's more to the story. This is the first spectral detection that unambiguously supports our liquid water-formation hypotheses for RSL."

So where does the water come from? Scientists think it comes from underground, when temperatures rise enough to melt sub-surface ice. When the melt-water reaches the slopes, it occasionally bursts onto the surface.

"It took multiple spacecraft over several years to solve this mystery, and now we know there is liquid water on the surface of this cold, desert planet," says Michael Meyer, lead scientist of NASA's Mars Exploration Program. "It seems that the more we study Mars, the more we learn how life could be supported and where there are resources to support life in the future."

The Hubble Space Telescope has been invaluable in studying the behaviours and developments of other galaxies in comparison to our own

Andromeda Galaxy more like Milky Way than previously thought

Hubble brings us closer to understanding the nature of blue star masses in our neighbouring spiral galaxy

A recent initiative to inspect the Andromeda Galaxy (M31) has revealed it has a similar percentage of newborn blue star clusters (based on mass) as the Milky Way. Located 2.5 million light years away, Andromeda has been re-created using 414 mosaic images captured by NASA's Hubble Space Telescope and the results are helping scientists determine the composition of our galaxy in the wider universe.

Capturing said percentage all comes down to determining the masses of stars within a given cluster, otherwise known as its Initial Mass Function (IMF). Nailing down this empirical function enables scientists to study a galaxy's formation from the light that passes through from distant sources.

The data has been taken from NASA's panoramic survey of the neighbouring galaxy, the Panchromatic Hubble Andromeda Treasury (PHAT), which consists of a staggering 8,000 images of 117 million different stars. Only stars roughly the same distance

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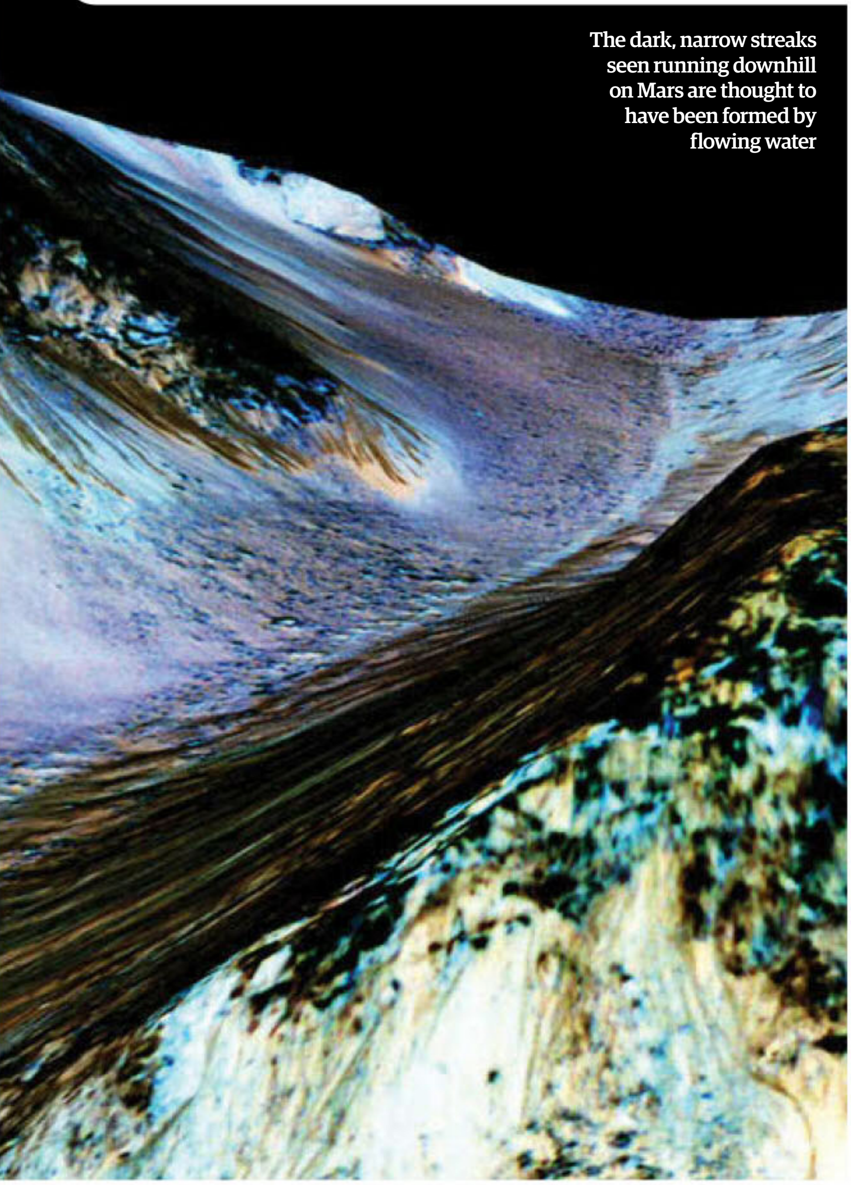


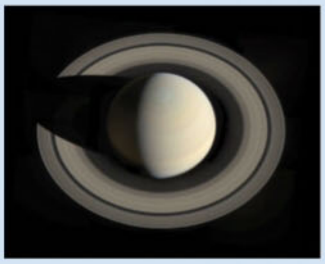
The dark, narrow streaks seen running downhill on Mars are thought to have been formed by flowing water

from the Earth (around 2.5 million light years) were used, generating huge amounts of data for NASA to study.

However, given the mountain of information gathered alongside these images, it would have taken scientists a long time to analyse every shred of it on their own. Thankfully, volunteers have been on-hand. "Given the sheer volume of images, our study of the IMF would not have been possible without the help of citizen scientists," says Daniel Weisz of the University of Washington in Seattle. "The efforts of these citizen scientists opens the door to a variety of new and interesting scientific investigations, including this new measurement of the IMF."

While analysing the data, scientists discovered that the IMF of Andromeda is very similar across all clusters surveyed. This suggests that star births are often uniform in part, generating a consistent distribution that covers everything from blue supergiants to small red dwarfs. "It's hard to imagine that the IMF is so uniform across our neighbouring galaxy given the complex physics of star formation," Weisz adds. Studying the IMF of the Andromeda Galaxy reveals another interesting insight into its origins – it's now theorised that a galaxy like M31 would have had fewer heavy elements with which to form planets, due to a lack of supernovae to draw from. ■

> "The data consists of a staggering 8,000 images of 117 million different stars"



Saturn's rings fully illuminated by the Sun and as imaged by Cassini

Saturn's rings warp and expand when cooling

A new study conducted by Cassini sheds new light on the planet's rings during its equinox

The composition and behaviour of Saturn's orbiting phenomena have fascinated astronomers for centuries, but new information has provided a new insight into its cooling habits following the equinox. The second largest planet in our Solar System, Saturn orbits the Sun every 29 years, meaning said equinox is one of only two times in its orbit when these rings are illuminated. Cassini observed this event back in August 2009 – Saturn's rings have been cooling ever since, revealing that some layers aren't cooling as quickly as expected.

"For the most part, we can't learn much about what Saturn's ring particles are like deeper than one millimetre below the surface," says Ryuji Morishima of NASA's Jet Propulsion Laboratory. "But the fact that one part of the rings didn't cool as expected allowed us to model what they might be like on the inside."

Scientists had previously theorised that the outermost main layer, categorised as 'A ring', was made up of a fluffy, snow-like ice covered in a pulverised outer layer known as regolith. However, Cassini's findings suggest this layer is largely pieces of icy debris. "A high concentration of dense, solid ice chunks in this region of Saturn's rings is unexpected," says Morishima. "Ring particles usually spread out and become evenly distributed on a timescale of about 100 million years." ■

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SOHO finds 3,000th comet

The Solar and Heliospheric Observatory (SOHO), a joint venture between NASA and ESA, has discovered its 3,000th comet. Set up in 1995 to observe and document the presence of comets in our galaxy, SOHO made the discovery on Sunday 13 September.

The Moon is shrinking

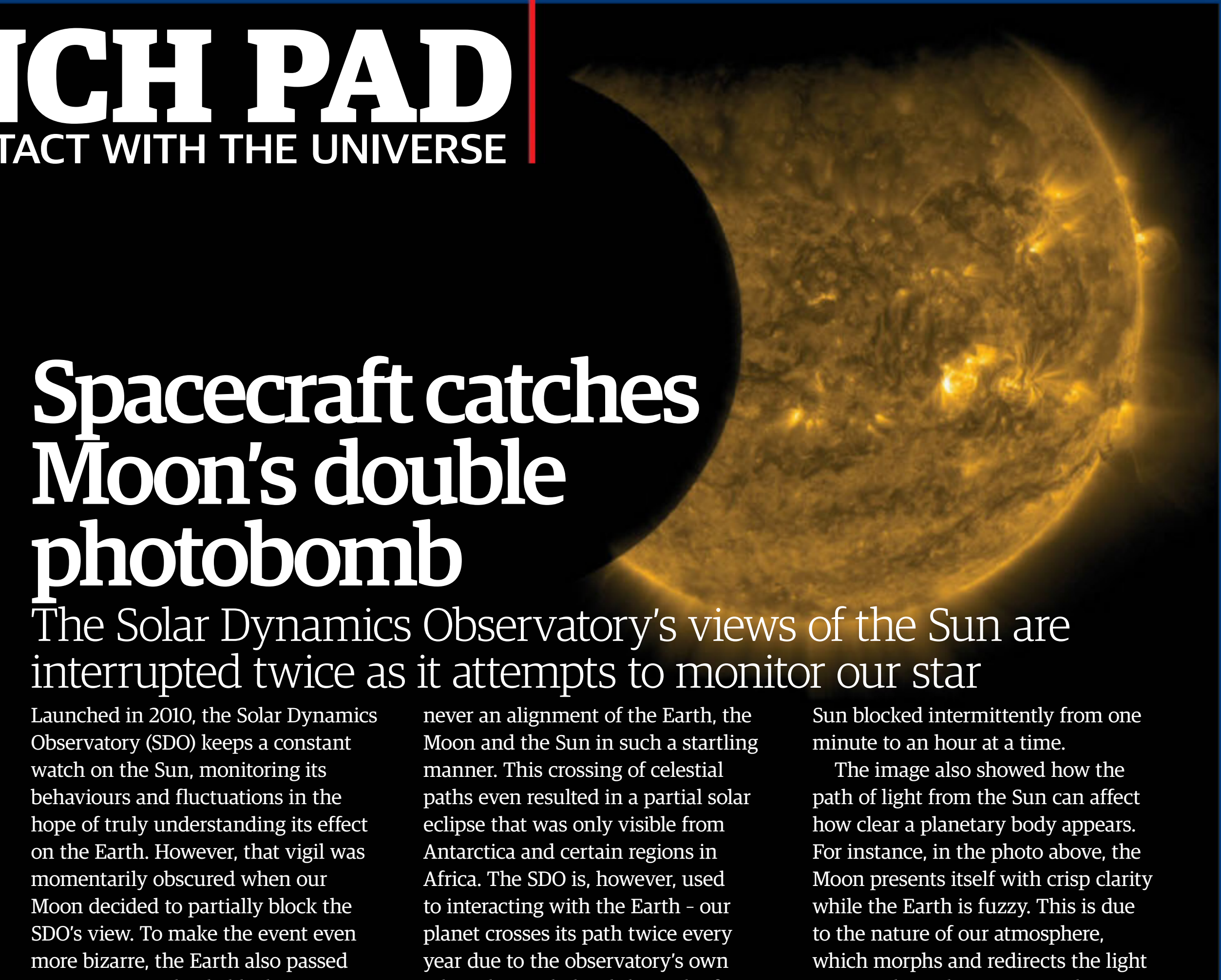
According to new results taken by NASA's Lunar Reconnaissance Orbiter, the gravitational pull of the Earth is influencing the movement of thousands of faults on the surface of the Moon, causing it to effectively shrink and warp.

Astronaut eyes space-time record

US astronaut Scott Kelly is currently six months into his year-long mission aboard the ISS – should he remain on board for a total of 342 days, he will break the record for the longest consecutive stay in orbit by a NASA astronaut.

Orion delayed until 2023

The Orion spacecraft, which is set to be launched by the new NASA Space Launch System (SLS), was originally pencilled in for a human test flight in 2021, but reports suggest the programme is unlikely to launch until 2023 at the earliest.



This image was taken through extreme ultraviolet wavelengths. While this type of light is invisible to the naked eye, it's typically coloured gold when captured through an ultraviolet lens

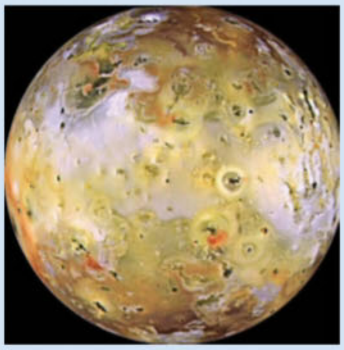
Spacecraft catches Moon's double photobomb

The Solar Dynamics Observatory's views of the Sun are interrupted twice as it attempts to monitor our star

Launched in 2010, the Solar Dynamics Observatory (SDO) keeps a constant watch on the Sun, monitoring its behaviours and fluctuations in the hope of truly understanding its effect on the Earth. However, that vigil was momentarily obscured when our Moon decided to partially block the SDO's view. To make the event even more bizarre, the Earth also passed into view, completely blocking any sign of our home star in the process.

The SDO has witnessed a number of lunar transits since its launch, but never an alignment of the Earth, the Moon and the Sun in such a startling manner. This crossing of celestial paths even resulted in a partial solar eclipse that was only visible from Antarctica and certain regions in Africa. The SDO is, however, used to interacting with the Earth - our planet crosses its path twice every year due to the observatory's own orbit taking it behind the path of our planet's. These phases usually last between two and three weeks, with the spacecraft's line of sight to the Sun blocked intermittently from one minute to an hour at a time.

The image also showed how the path of light from the Sun can affect how clear a planetary body appears. For instance, in the photo above, the Moon presents itself with crisp clarity while the Earth is fuzzy. This is due to the nature of our atmosphere, which morphs and redirects the light passing through it creating a haze-like effect. Conversely, the Moon has no atmosphere so its photobombing exploits remain crystal clear.



Io is the most volcanically active object in the Solar System

Magma oceans could help find Io's 'misplaced' volcanoes

Underground flows may be the key to finding Jupiter moon's peaks

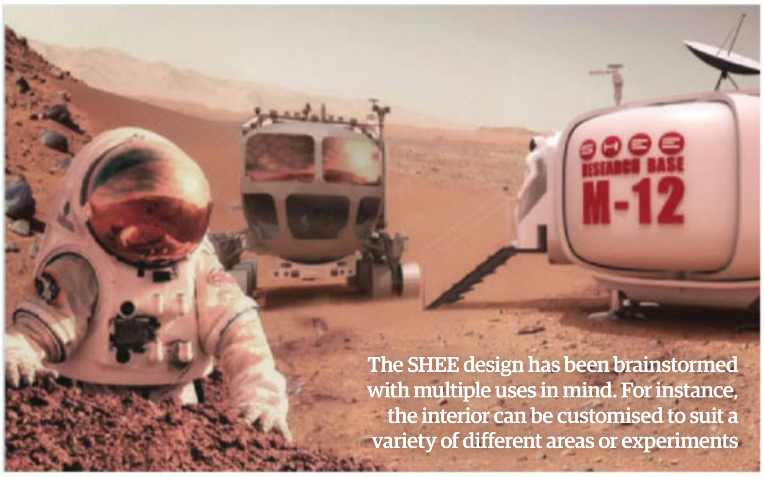
Jupiter's moon Io, which happens to be the most volcanically active world in our Solar System, is the site of a mystery that's captivating scientists. A series of previously documented volcanoes aren't appearing in the exact locations expected, with new research suggesting subterranean oceans of magma and water are to blame.

"This is the first time the amount and distribution of heat produced by fluid tides in a subterranean magma ocean on Io has been studied in detail," says Robert Tyler, who divides his time between the University of Maryland, College Park and NASA's Goddard Space Flight Center. "We found that the pattern of tidal heating predicted by our fluid-tide model is able to produce the surface heat patterns that are actually observed on Io."

The research implies that Io, which is severely affected by the gravitational pull of the gas giant they orbit and fellow moon Europa, is warped in shape and size by this galactic tug of war, forcing its underground magma flows to shift and undulate. These huge torrents forced eruption points to distend or shift, knocking their positions off course.

Self-building habitats for alien world colonisation in development

Europe-led project aims to deploy first terrestrial and space habitats on Mars and beyond



The SHEE design has been brainstormed with multiple uses in mind. For instance, the interior can be customised to suit a variety of different areas or experiments

While the space agencies of the world continue to pursue the dream of manned expeditions to Mars and beyond, a new initiative involving a consortium of five European nations is designing a series of domiciles for when the first astronauts get there.

However, these aren't just any homes. The Self-deployable Habitats for Extreme Environments (SHEE) have been designed to build themselves in locations too adverse for direct human involvement. The brainchild of architect and assistant professor of human-centered design and aerospace engineering at the Florida Institute of Technology, Ondřej Doule, the project is the centrepiece of a 36-month long, €2.3-million (£1.7-million/$2.6-million) investment from five European nations.

The construct itself, consisting of rigid, inflatable and robotic components, will form automatically once activated on a given surface, providing five separate areas of habitable space: entrance ports, work areas, a kitchen, a toilet and private crew quarters. While a functioning prototype is some way off in the distance, Doule has confirmed that they have moved beyond the design stage and that "lab tests are ongoing."

"As with every prototype, there are issues that have to be addressed after first uses and transport, and also continuous integration that started in Estonia, so we are optimising the system instantly," explains Doule.

Once the system is operational, the plan is to conduct "no-humans-in-the-loop tests and operations", to confirm that SHEE can operate for up to two weeks in an extreme environment. Tests will take place at the International Space University in Strasbourg in the coming months.

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DARK MATTER

Written by David Crookes

85 per cent of reality is missing. **All About Space** sheds light on the secret controlling the fate of the universe

When you look up at the night sky, you'll see millions upon millions of illuminated objects, from the Moon and stars to the planets in our Solar System. It is easy to think that they make up the bulk of what exists in the universe but, in fact, what can be viewed is a tiny fraction of what is there. What you can't see is an invisible yet important entity called dark matter, which makes up 22 per cent of the cosmos. That may strike you as odd since there is six times more dark matter than the normal matter that comprises everything we can see and touch, but as one of astronomy's deepest mysteries, it looks set to take decades to unravel its secrets.

Dark matter has been confounding and fascinating astronomers for more than 80 years, not least because it is unlike the normal matter that we find here on Earth. It is not composed of baryons, the 'normal matter' particles that make up the planets, stars and even ourselves. It does not emit or absorb light and it cannot be directly observed with our very own eyes. About the only thing astronomers know with some certainty is that dark matter interacts through gravity. As for the rest, it's fair to say astronomers understand more about what dark matter is not, than what it actually is. "It's all a bit embarrassing," Richard Massey, an astrophysicist at Durham University's Institute for Computational Cosmology, tells **All About Space**. "There are lots and lots of theories about what it could be, but you could take a theorist and put him in a room for a

Pascal Pralavorio, using the LHC's ATLAS detector, is seeking the particles that could make up dark matter

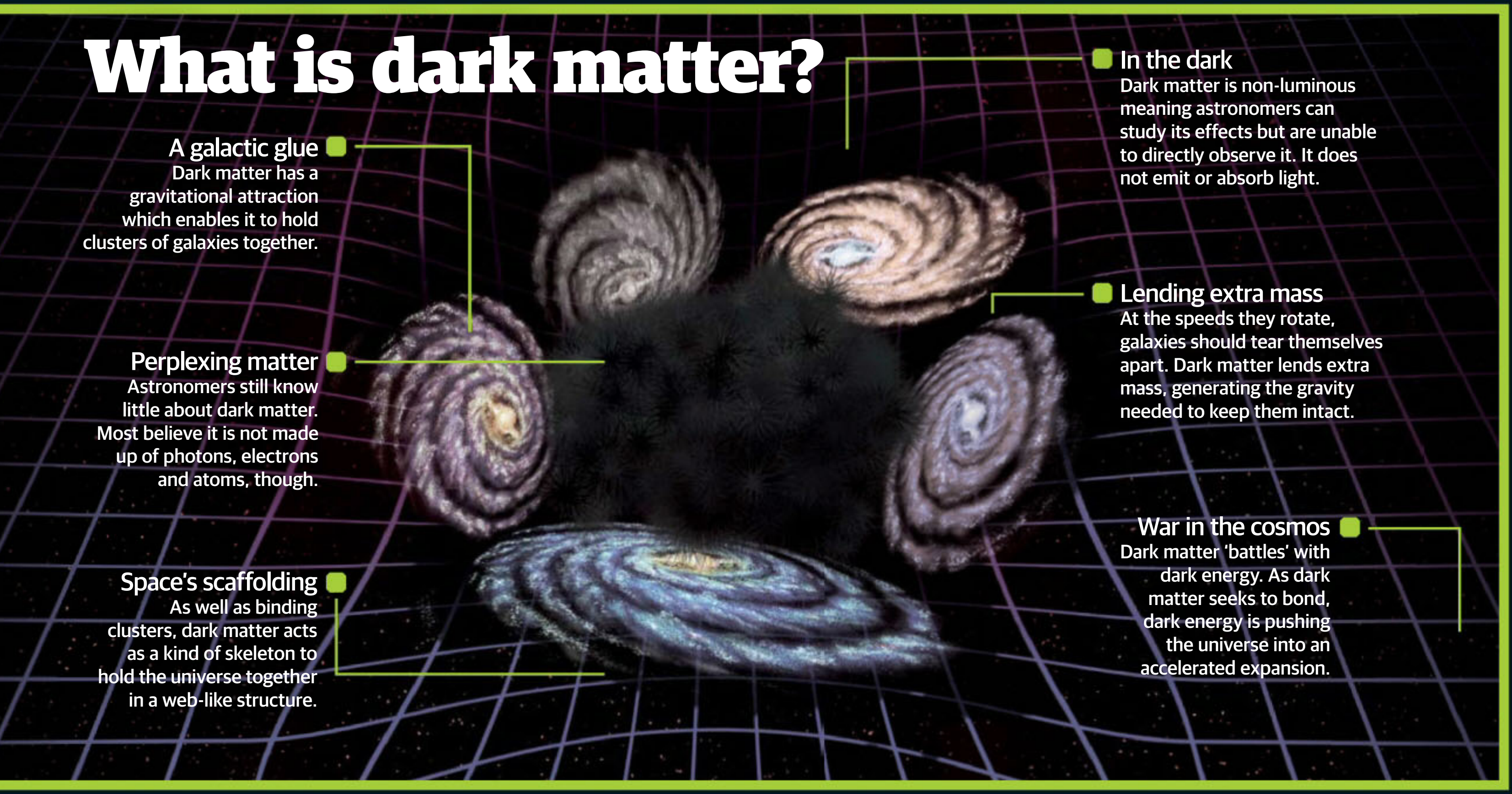
day with a pencil and he will come up with another theory. We've had decades to think about dark matter so there's a lot of ideas about what it is and what it could do but, honestly, we have no clue. It could be any or none of them."

Dark matter was first 'observed' in 1933 by Swiss astronomer Fritz Zwicky, who had argued - correctly - that galaxies moved in relation to one another within clusters. It was during his study of the Coma Cluster, that he noted the rapidly moving galaxies did not have enough visible matter to provide the necessary gravity to hold them together. In order to explain what he was seeing, he concluded that there must be lots of unseen matter. At the time, however, his findings were largely ignored.

Gradually, though, the idea of an invisible material became the accepted wisdom. In the Seventies, astronomer Vera Rubin found that single galaxies as well as clusters also had hidden mass and she discovered that the stars orbiting black holes at the centre of spiral galaxies maintained the same speed no matter how far away they were from it. This kind of behaviour struck her as being particularly unusual since the black holes provide gravity, just as the Sun does for the planets in our Solar System. The difference is, the further away planets are from the Sun, the slower they complete their orbit. To explain why stars keep a constant speed regardless of their position around a black hole, Rubin believed something else must be providing the gravity.

That something else is dark matter, the stuff which binds galaxies together. Forming an invisible halo around a galaxy which extends beyond its edge, it also keeps the rotation speed constant. Dark matter is believed to have been present at the time of the Big Bang, eventually condensing to form the backbone on which everything else in the universe is built. As the universe formed and dark matter clumped, its massive weight exerted gravity on the visible, normal matter objects around it, pulling them in and helping galaxies to form. The gravitational attraction is so great that it prevents the galaxies from splitting and affect the speeds at which they travel in a cluster.

But what is this elusive mass made up of? That is the question astronomers are keen to answer and so far science has drawn a blank. Experts have considered dark matter consisting of antimatter, the opposite of matter, but they haven't seen the unique gamma rays that are produced when antimatter meets matter and the pair destroy each other. Massive compact halo objects (MACHOs), brown dwarfs, white dwarfs and black holes have also been looked at as explanations but they have been ruled out because dark matter comprises 85 per cent of all matter in the universe and there just aren't that many of these objects to account for such a large heft. There is a potential for dark matter to be made up of neutrino or axion particles. But astronomers believe it is more likely to include something entirely different given that the behaviour of



What is dark matter?

A galactic glue
Dark matter has a gravitational attraction which enables it to hold clusters of galaxies together.

Perplexing matter
Astronomers still know little about dark matter. Most believe it is not made up of photons, electrons and atoms, though.

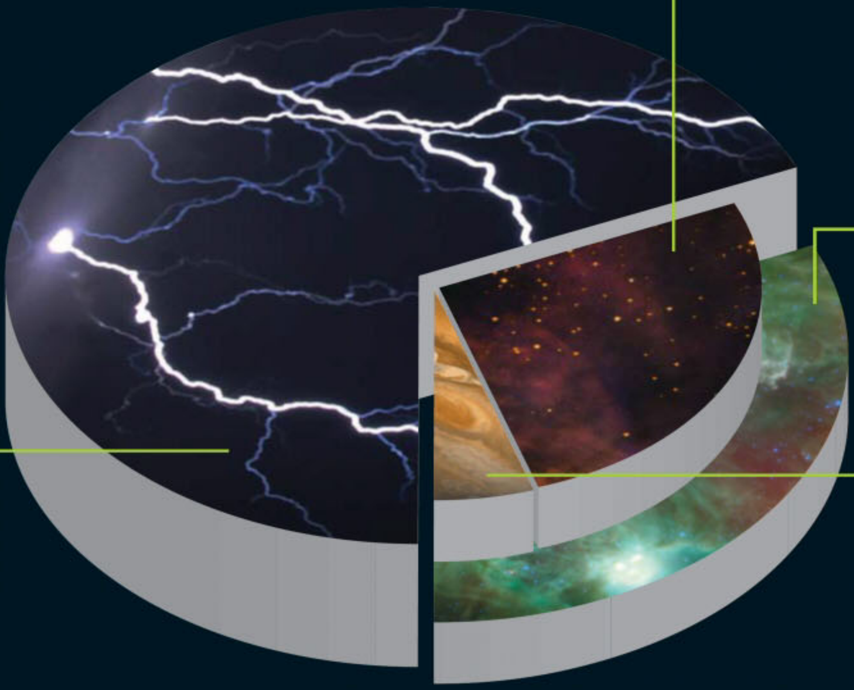
Space's scaffolding
As well as binding clusters, dark matter acts as a kind of skeleton to hold the universe together in a web-like structure.

In the dark
Dark matter is non-luminous meaning astronomers can study its effects but are unable to directly observe it. It does not emit or absorb light.

Lending extra mass
At the speeds they rotate, galaxies should tear themselves apart. Dark matter lends extra mass, generating the gravity needed to keep them intact.

War in the cosmos
Dark matter 'battles' with dark energy. As dark matter seeks to bond, dark energy is pushing the universe into an accelerated expansion.

What is the universe made of?



26.8%
Dark matter
Over 25 per cent of our universe is made up of dark matter – just over five times that of normal.

31.7%
All matter
Take dark energy out of the equation and the amount of matter in the universe is 85% dark and 15% normal.

68.3%
Dark energy
Astronomers believe dark energy makes up the majority of our universe. It's thought that this mysterious form of energy will become more dominant in the future.

4.9%
Normal matter
Normal matter – the visible substance making up the baryonic matter we can observe – comprises a small per cent of the universe.

those particles do not fully explain the indirect observations of dark matter. They label the potential dark fundamental particles as weakly interacting massive particles (WIMPS) and while this still fails to actually explain what they are, it at least points to one of the hallmarks of dark matter: the fact that its particles can pass through normal matter and other dark matter particles. "Dark matter doesn't interact with our particles or other dark matter particles except through gravity," explains Massey. "If you put your hand down on the table, it doesn't go through the table because of the electromagnetic force. That's what pushes atoms apart from each other. It's the same with a car crash – electromagnetic forces stop the car and crumple it up. With dark matter, it seems, everywhere we looked were lumps of dark matter that had smashed into each other like a big car crash. But they just passed straight through each other and they didn't care. They also passed through ordinary matter and just kept going. We concluded that dark matter doesn't interact with the electromagnetic force."

It is perhaps ironic, then, that one of the methods being used to detect the individual particles of dark matter involves smashing protons together at close to the speed of light. Such a thing is taking place in the 27-kilometre (17-mile) long underground complex that is the Large Hadron Collider (LHC) near Geneva. Scientists at the European Organization for Nuclear Research (CERN) in Switzerland resumed the smashing of particles in June. "If dark matter is really a new particle, then it should have a special characteristic," says Pascal Pralavorio, a physicist at CERN who works on the LHC's ATLAS detector, which is seeking the particles that could make up dark matter. "It should be long-lived and go at a relatively slow speed compared to the speed of light. But we know nothing about these particles – we don't know their mass, for example. We are trying to search everywhere."

In trying to re-create the primordial blast of 13.8 billion years ago, CERN scientists hope that the particles which make up dark matter may be spotted. Pralavorio thinks that there could be one, two, three, or more dark matter particles, but resigns himself to the fact that we just don't know yet. With the LHC's beam energy level being cranked up, scientists are looking for missing transverse energy, which is an imbalance in momentum before and after a particle collision. "But the way we are looking at it is paradoxical," Pralavorio adds. "These particles, if they were to exist, would leave no hint at all in our detectors so we will see them by the absence of seeing them."

If it seems like a stab in the dark, then it is to a degree. "We are kind of in the dark for the time being," says Pralavorio. "It's like entering a new world of experiments and, in principle, it is possible that dark matter doesn't even exist." In order for it not to exist, though, the physicist explains that "gravity would have to be modified compared to what we know". But since, this, in principle, has been tested in the Eighties and Nineties and the conclusion is that it is not possible to explain the dark matter phenomena by modifying the gravity, the probability is that it is a new particle. And so the search continues.

Scientists are using a variety of instruments in the hunt ranging from the Large Hadron Collider and telescopes to antimatter detectors, cosmology instruments and gamma-ray detectors – NASA's Fermi Gamma-ray Space Telescope could possibly detect dark matter collisions, for example. Hundreds of galaxies have been analysed and they are seen to behave in the same way, displaying speeds at which they rotate that do not match their visible mass. In April this year, Massey led aZ team of scientists which used the Hubble Space Telescope to view four distant galaxies at the centre of a cluster 1.3 billion light years away from Earth. Lots of the collisions showed that dark matter didn't interact, slow down or become destroyed. But there was an extra one – a single galaxy falling into a cluster of galaxies, which is something that happens over a longer period of time – that showed dark matter didn't end up where it was expected. Instead, it appeared that one of the dark matter clumps was lagging behind the galaxy it surrounded, leaving it some 50,000 million million kilometres (31,000 million million miles) away. This was an intriguing discovery because it showed dark matter may be able to interact with forces other than gravity otherwise it would have remained close and kept up to speed. "It points to a very gentle source tugging at the dark matter, very, very slowly for billions of years resulting in an appreciable net force," says Massey. This showed the lag and pointed to a possibility of dark matter's self-interaction. It

> "We've had decades to think about dark matter so there's a lot of ideas about what it is and what it could do" **Richard Massey**

Dark matter vs dark energy

How the universe could end depends on who wins in a cosmic tug of war

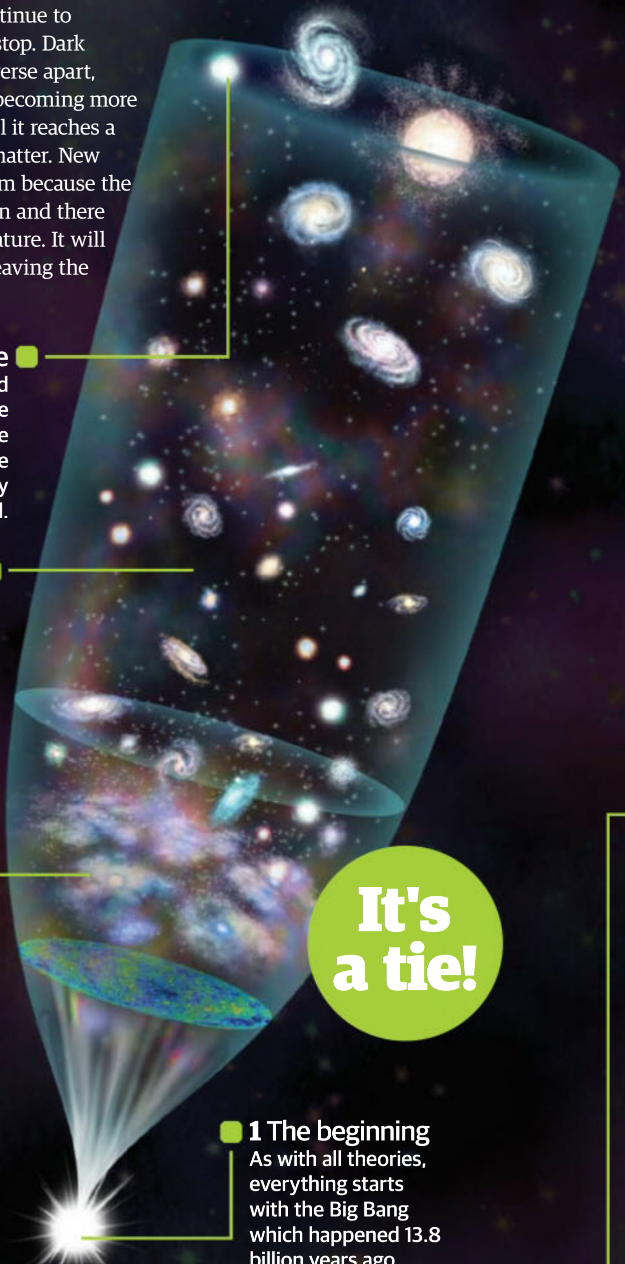
Big Freeze

Rather than rip apart, there is a theory that the universe will continue to expand and then simply stop. Dark energy will push the universe apart, with the energy inside it becoming more and more spread out, until it reaches a balance point with dark matter. New stars will be unable to form because the supplies of gas are too thin and there will be a uniform temperature. It will result in the Big Freeze, leaving the universe dead and empty.

Big Crunch

For the 'Big Crunch' to occur, gravity would slow expansion and drag objects back, collapsing the universe in on itself. There would need to be enough matter with a density greater than critical density to exert the required gravitational force. It would also mean dark matter dominating over dark energy. The result would be the creation of the largest ever black hole - or the ignition of another, reforming, Big Bang.

Dark matter wins



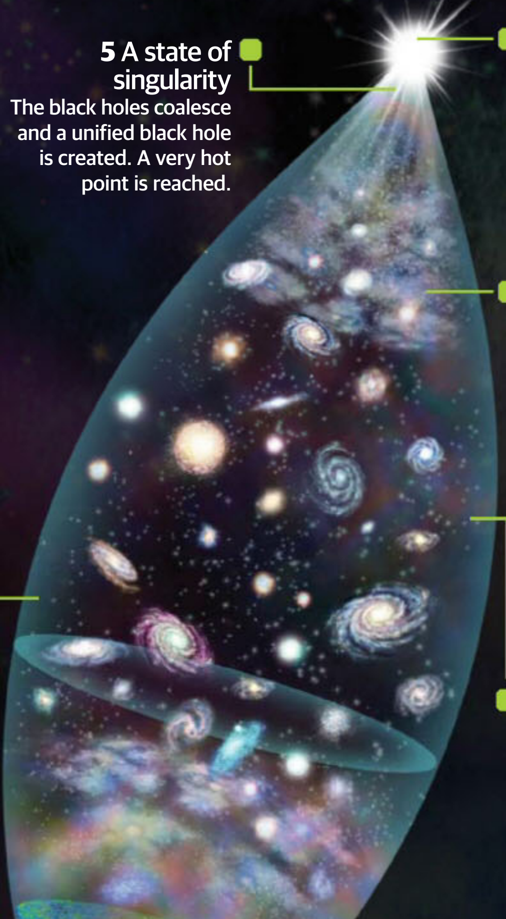
It's a tie!

4 The Big Freeze
The universe cools and heat death results: stars die and matter decays since there is no temperature difference to allow energy to be consumed.

3 Continuing to expand
As the universe expands, the space between the clusters of galaxies will grow. The gases needed for star formation run thin.

2 Period of expansion
The universe has been expanding for billions of years. It began accelerating 6 billion years ago and heat is being dispersed.

1 The beginning
As with all theories, everything starts with the Big Bang which happened 13.8 billion years ago.



5 A state of singularity
The black holes coalesce and a unified black hole is created. A very hot point is reached.

6 Start again
The singularity is incredibly dense and, in theory, it could spark another Big Bang, starting the whole cycle over again.

4 Black hole
As galaxy clusters are pulled closer and merge, stars explode and black holes emerge as the universe collapses under its own gravity.

3 Greater density
The density of the universe is greater than the critical value. Gravity is increased and starts to contract the universe.

2 Reaching a maximum
The Big Crunch theory supposes space is a positive constant curvature, or a closed universe. If so, a maximum expansion is reached.

1 Universe expands
The universe is currently expanding and it will continue to do so for many more billions of years.

KEVIN PIMBBLET

Astronomer at the University of Hull, UK, and Monash University, Australia

"We know that the universe is expanding and accelerating in its expansion. We also know that its geometry is all but flat (which means angles in a triangle add up to 180 degrees). What we don't know is how powerful dark energy is. For this reason, the current best bet for me is that the universe will carry on expanding forever. If dark energy is shown to be stronger, then I'm willing to change my mind and opt for a Big Rip instead!"

NEMANJA KALOPER

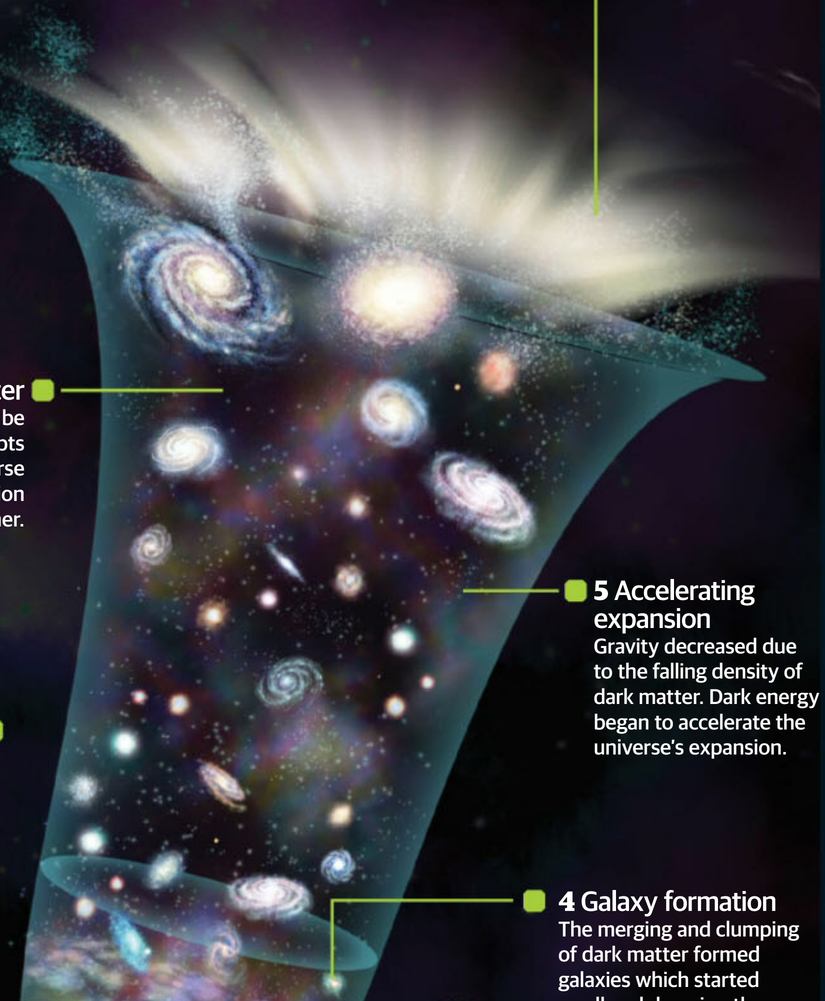
Professor of physics at the University of California, Davis

"Since particles have a mass, the universe must have a finite volume and time range, so it must crunch in the future. The current phase of acceleration cannot last forever, but is merely a transient phase. Dark energy cannot ever remain constant, which preordains the universe to collapse."

Dark energy wins

Big Rip

It was once widely thought that the gravitational pull of the universe would cause its expansion to slow down but evidence points instead to an acceleration. Indeed, the gravitational attraction of dark matter began to weaken 8 billion years after the Big Bang, putting dark energy in a dominant position. This appears to be pushing the universe apart and, if it continues to speed up, the constituents of matter could start to separate, causing the Big Rip.



7 Torn apart
Eventually everything from the galaxies to the planets, stars and subatomic particles would be ripped apart.

6 Faster and faster
Should gravity be thwarted in its attempts to make the universe collapse again, expansion would accelerate further.

5 Accelerating expansion
Gravity decreased due to the falling density of dark matter. Dark energy began to accelerate the universe's expansion.

3 Dark energy
Around 6 billion years ago, the density of dark energy exceeded the density of dark matter for the first time.

4 Galaxy formation
The merging and clumping of dark matter formed galaxies which started small and drew in other objects to become larger.

2 Dark matter
Dark matter exceeded the density of dark energy for billions of years. It made up about 63% of the universe when it was just a few hundred thousand years old.

1 The Big Bang
Dark matter and dark energy are said to have originated at the point of the Big Bang, following which atoms were formed.

EELCO VAN KAMPEN

Astronomer at ESO

"Dark energy competes with gravity (due to matter, including dark matter) to determine the fate of our universe. Gravity pulls things together, while dark energy tries to expand everything away from each other even more than it currently does: it accelerates the expansion of our universe. How fast that happens depends on the nature of the dark energy: in the most extreme case, it causes everything, including atoms, and finally space-time itself, to rip apart: this is the 'Big Rip'."

is not conclusive and more studies are needed, but Massey says: "If it's verified then there is no doubt it is very significant."

"What we saw was a bit of a mystery," he adds. "We saw the kind of thing that would be predicted if dark matter particles were bouncing off each other, without actually witnessing it first hand. But it's such an important thing if it's true that we're busy trying to check if there is any other way to cause this kind of observational effect that we saw."

Scientists 'see' dark matter using a precise technique called gravitational lensing which relies on dark matter's ability to deflect light rays. The path that the light follows around dark matter lets astronomers map its distribution. "Fortunately big lumps of dark matter bump into each other from time to time, just as galaxies bump into each other as they whizz around the cosmos," says Massey. "So what we've been doing is using the Very Large Telescope in Chile to look at those places in the universe where lumps of dark matter and ordinary material happen to have bumped into each other. We watch for the trajectories of dark matter and see whether it has slowed down at all and whether it's changed direction or converted into something else. We also look to see whether some of it disappeared in the collision." Certainly, Massey feels dark matter should interact in some way, at a very low level at least. "We know that because dark matter was created in the first place and so it must have been created through some sort of interaction. Even in the universe 13 billion years later there will be some very low level residual," he says. In general, though, it has been seen that when two galaxies collide, they merge without any issue with various elements smashing into each other, pointing to the gravitational field of the galaxies.

One thing that can be said for certain is that there is a finite amount of dark matter. Dr Massey says measurements began being taken ten years ago to see how much dark matter there is in the universe at different times. "Wherever we look, there seems to be a fixed amount of it, just like with ordinary matter," he explains. "But as the universe gets bigger, it gets stretched and diluted. Eventually it could get so stretched, it pulls itself apart but dark matter's gravity pulls it together. It's like when you throw up a ball and gravity brings it back down again, keeping everything nice and steady on the ground. If you explode out of the Big Bang, then gravity will pull everything back together and keep everything intact."

But in 1998, an astonishing find was made by two teams of astronomers using the Hubble Space Telescope. The High-Z Supernova Search Team and the Supernova Cosmology Project were studying distant exploding stars, or supernovae as they are referred to, and noted that they appeared to be unexpectedly dimmer. The observations pointed to the stars being further away than the calculations suggested they should be, especially given that, up until that point it was firmly believed the expansion of the universe was slowing down. This led to the startling conclusion no one was expecting: that the expansion of the universe was actually speeding up. If we use Massey's example of the ball being thrown into the air, this is akin to it being propelled upwards and continuing to rise at faster and faster speeds forever more. On Earth, gravity would pull it back down and in space, dark matter exerts a gravitational pull, which should rein in such acceleration. So how could the universe be speeding up? After much checking of the data, astrophysicists came up with a hypothesis which said the universe was expanding because of a repulsive gravity. This has been labelled dark energy. Einstein had theorised such a thing decades before. His theory of gravity made mention of a cosmological constant which predicted that empty space is able to possess its own energy. But while he later called the constant his biggest blunder, it has since proved not to be. For astronomers believe that, as the universe expands, more dark energy appears. The overall global effect of this leads to an ever greater repulsive force which continues to accelerate the speed of expansion. Since dark energy is not evenly distributed throughout the universe, it has been shown to 'override' the gravitational pull of dark matter. These were astonishing findings and it was no surprise when scientists Saul Perlmutter, Adam Riess and Brian Schmidt shared the 2011 Nobel Prize in physics for their work. "There's a pull-versus-push thing going on between dark energy and dark matter - a titanic tug of war," says Massey. "But dark energy is just as mysterious still and we know even less about it than we do dark matter. There are lots of big experiments trying to measure both together and work out the balance between them and what all of these things do."

As you would expect, this has a potentially huge effect on the universe as a whole. The gravitational pull of dark matter is failing to prevent the universe from accelerating and so it gets bigger and bigger. There is a possibility the universe will expand so fast that it overstretches, the consequence of which could be the eventual tearing of the universe. This is something theorists call the 'Big Rip'. At the same time, dark energy is becoming ever more dominant. Today 26.8 per cent of the universe is dark matter, around 4.9 per cent is normal matter and dark energy makes up the remaining 68.3 per cent. But dark energy's percentage is higher than it used to be and dark matter's percentage is lower. Dark energy gained the upper hand around 6 billion years ago and dark matter's percentage share will continue to fall in relation to dark energy as the latter feeds off it. Should this continue, the growth of structures such as galaxies could slow. Indeed, in 2011, NASA reported that a five-year study of 200,000 galaxies stretching back 7 billion years in cosmic time independently confirmed dark energy was driving our universe apart at accelerating speeds.

All of which makes the dark universe a fascinating study. "If dark matter particles exist, then it means we have physics beyond the model that we know very well and that explains all phenomena we are seeing," says Pralavorio. "It will need new theory to explain this in the next decade." Indeed, dark energy, dark matter and matter/anti-matter symmetry is a key direction for 21st century astrophysics. "Dark matter could have a role - dark energy for sure could have a higher role. It could change the field of particle physics," says Pralavorio. "And we are not at the end of the surprises."

Making a dark matter map

From the ground and space, astronomers are building a picture of the dark universe

The Large Synoptic Survey Telescope

Currently being built in Chile, the LSST will map the visible sky using a mix of strong and weak gravitational lensing.

Gravitational lensing

Gravitational lensing relies on concentrations of matter bending light from a more distant source. It allows astronomers to measure the dark universe.

The LSST telescope in Chile will aim to measure the dark universe using strong and weak gravitational lensing

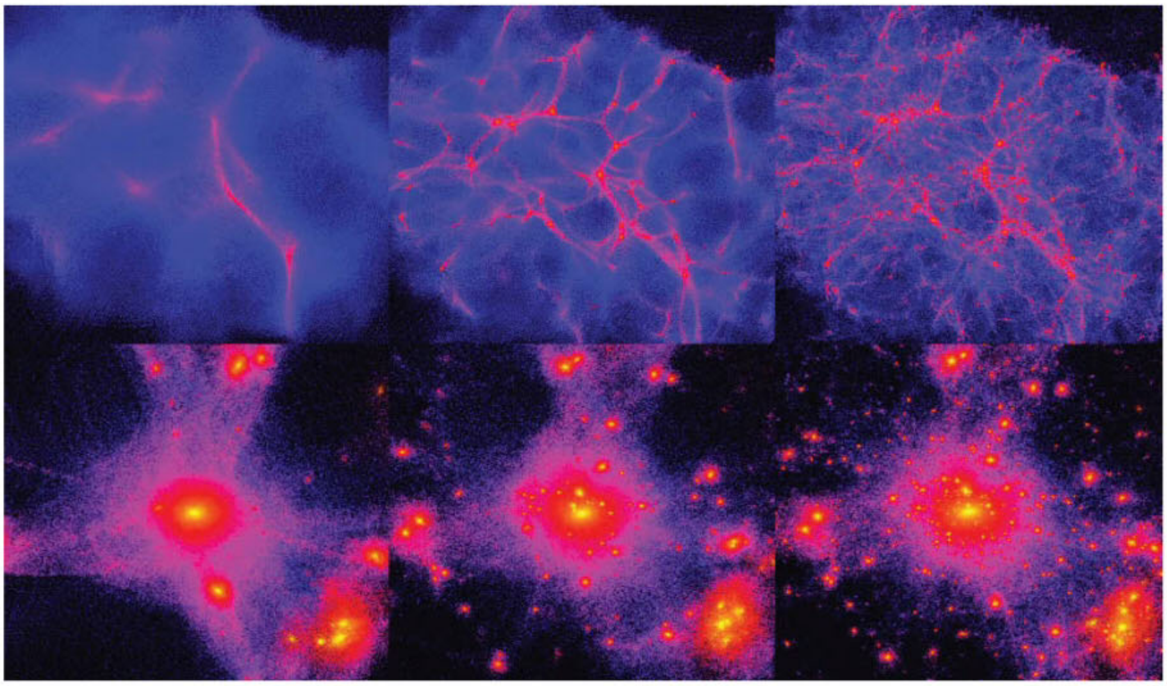
Introducing Euclid
Euclid is an ESA mission which seeks to map the geometry of the dark universe. It will launch in 2020.

Plotting the evolution
By mapping the 3D distribution of 2 billion galaxies and their dark matter and dark energy, astronomers can plot the evolution of the universe.

Measuring expansion
The telescope will point to a position in the sky to accurately measure the accelerated expansion of the universe, getting a better understanding of dark matter and dark energy.

Taking snapshots
The telescope will feed a visible-light camera and a near-infrared camera/spectrometer.

Hot, warm and cold dark matter



Cold dark matter

The cold dark matter theory is favoured by most astronomers. It posits that cold dark matter particles move much more slowly than the speed of light. This means they possess lower energies and have an increased chance of growing hierarchically since they can attract and merge with each other, forming large-scale structures.

Warm dark matter

Warm dark matter sits between cold and hot matter. Structures are formed from the bottom-up, as with cold dark matter where the distribution can grow denser and more massive. They also form from the top-down, in the manner of hot dark matter. Warm dark matter particles move at a higher speed than cold dark matter but slower than hot.

Hot dark matter

Possessing high energy and travelling at speeds that are close to or at the speed of light, hot dark matter is composed of particles with zero or near-zero mass and no electric charge such as neutrinos. It is a less favoured theory since the fast-moving particles are less likely to clump together, making early galaxy formation more difficult.

The AMS was taken up to the ISS by Space Shuttle Endeavour and installed on the exterior of the space station

Catching dark matter on the ISS

We talk to Paolo Zuccon, assistant professor of physics at MIT, about his hunt for the elusive dark matter using the AMS detector on the International Space Station

Do you believe dark matter exists?
We observe major gravitational effects that cannot be justified by the luminous matter - the stars, galaxies, hydrogen clouds - that we see. These gravitational effects include the classical rotation speed curve of the stars around the galaxy centre, and also more modern observations like the large-scale structure galaxy clusters and observations where the light is gravitationally bent by dark matter halos around a galaxy. The latter is called micro-lensing and it is one of the ultimate proofs that the dark universe contains more matter than the luminous one.

How does the particle-physics detector on the ISS look for dark matter?
The Alpha Magnetic Spectrometer (AMS) observes the flux - or energy - of cosmic rays. While most of the time, dark matter particles just sit in the galaxy halo, during a collision between two of them they may undergo an annihilation reaction. In such an annihilation, the dark matter particles disappear and ordinary particles are produced. These ordinary particles will decay and ultimately only stable particles will survive, namely protons, electrons, anti-protons and anti-electrons (positrons). The particles produced by dark matter will join the flux of the cosmic rays. Given the small 'natural', or expected, content of positrons and anti-protons, the additional contribution from dark matter annihilation might be relevant and then measurable.

What are scientists looking for?
The positrons and anti-protons from dark matter annihilation will have a characteristic energy distribution that is related to the mass of dark matter particles. In case of a dark matter contribution to the cosmic positrons, we would then expect an energy-dependent deformation of the expected positron flux. Collecting more data at high energy is very important because dark matter is just one of the hypotheses able to explain the positron excess.

The AMS is located on the exterior of the ISS. What benefit does this have?
This location is really important. First, being outside Earth's atmosphere allows us to avoid the possible background from particles produced in the collisions between cosmic rays and the atmosphere. Second, clearly having reached the orbit, we do not want any additional material above us, so we want to stay outside. Third, AMS is considerably large and it will not fit inside.

What do we know so far from data collected with the AMS about the origins of dark matter?
At this stage, we can only speculate. The observed features might have some dark matter origin but they also may not. Furthermore there are very different theories about dark matter's nature, so there are still a lot of possibilities. If confirmed, AMS data would point to a heavy dark matter particle.

How close are you to confirming this?
Dark matter particles must be different from what we have observed so far using particle accelerators. The effort now is to find some properties of these dark matter particles, in order to understand their nature and possibly open the door for new physics.

Is it possible that dark matter will not be found?
It is possible that we may find that the signals we observe with AMS are of astrophysical origin, and that they are not related to dark matter at all. This would also be really interesting, because we would have data about new processes in the universe. I believe that dark matter is out there. Unfortunately the poor knowledge we have about its nature makes it necessary to search for signals in many directions and only a few of them are supposed to succeed.

How interesting are these studies?
Dark matter is, for sure, one of the most interesting topics to find new frontiers. With the discovery of the Higgs boson, we put the cherry on top of the cake of the standard model. With dark matter we are really venturing into uncharted territory. It is tremendously difficult and we have to wander in many directions at the same time. But the prize is the discovery of new physics.

> "We're venturing into uncharted territory with dark matter. We have to wander in many directions at once" **Paolo Zuccon**

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3” reflecting telescope. Ready to use in seconds and so easy. This is a great starter telescope.

Supplied complete with table mount, side finder scope and two eyepieces.

f=300mm d=76mm.
Standard 1.25” eyepiece fitting.
4mm (75x) and 12.5mm(24x) eyepieces included.

Visionary STARLA^{80}

Quick to set up
Easy to use
Serious viewing

80mm objective refracting telescope. Sets up in minutes and really easy to use. This is a great starter telescope yet has all the features to grow with your hobby.

Supplied complete with full size tripod and AZ mount, side finder scope and two eyepieces.

f=900mm d=80mm.
Standard 1.25” eyepiece fitting
10mm (90x) and 25mm(36x) eyepieces included plus erecting 90° diagonal for easy all-round viewing.

Visionary MIRA CETI

1400/150 reflecting telescope outfit

OUT OF THIS WORLD

6” mirror reflecting telescope with full astronomical equatorial mount for those taking things a little more seriously.

Supplied complete with full size tripod and EQ2 mount, side finder scope and two eyepieces.

f=1400mm d=150mm. Standard 1.25” eyepiece fitting. 10mm (140x) and 20mm(70x) eyepieces included.

Visionary TELESTO

1000/114 reflecting telescope outfit

Making Astronomy fun

4.5” mirror reflecting telescope with full astronomical equatorial mount takes just a short time to set up and use. Great for the beginner wishing to learn all the basics of astronomy. Accepts all standard astro accessories, so the Telesto is ready when you are to go further. Compact tube design so it packs away in less space.

Supplied complete with full size tripod and EQ1 mount, side finder scope and two eyepieces.

f=1000mm d=114mm. Standard 1.25” eyepiece fitting. 12mm (83x) and 20mm (50x) eyepieces included.

Eyepieces from 4mm - 40mm

Divide the focal length of your telescope by the chosen eyepiece to find magnification.

With a Telesto for example, magnifications of 25x - 250x can be achieved with just a selection of extra eyepieces.

A huge range of camera adapters

Take night sky photographs with your SLR or compact camera - even your smartphone.

Filters

Fit quickly into our range of eyepieces to increase contrast and clarity.

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Explorer's Guide

Venus

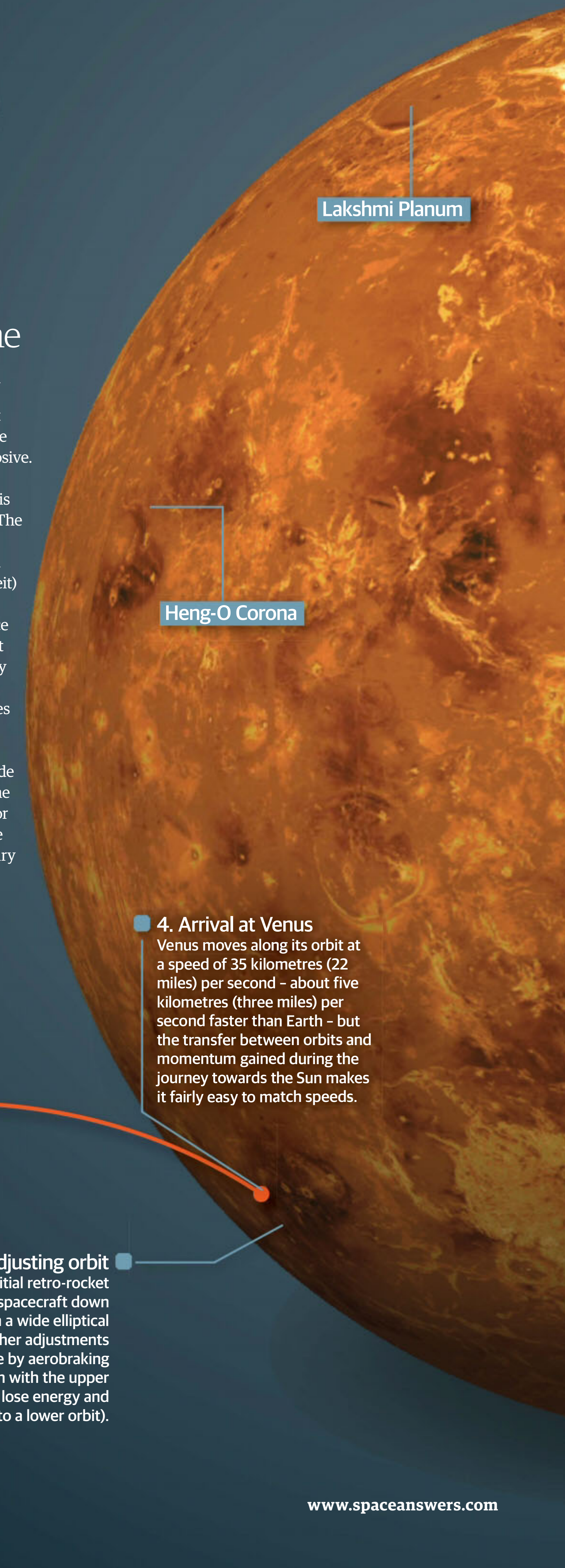
Our nearest neighbour in space is also the most hostile planet in the Solar System

After the Moon, Venus is usually the brightest object in Earth's night sky - a brilliant morning or evening 'star' usually seen either in the east before sunrise or in the west after sunset. Its perpetual loose attachment to the Sun is due to the relative positions of planets in the inner Solar System - as the second planet, Venus's orbit lies a little way inside Earth's, so it always lies in roughly the same direction as the Sun itself. For most of the time, Venus is the closest major planet to Earth, and what's more, it is also Earth's near-twin in terms of size.

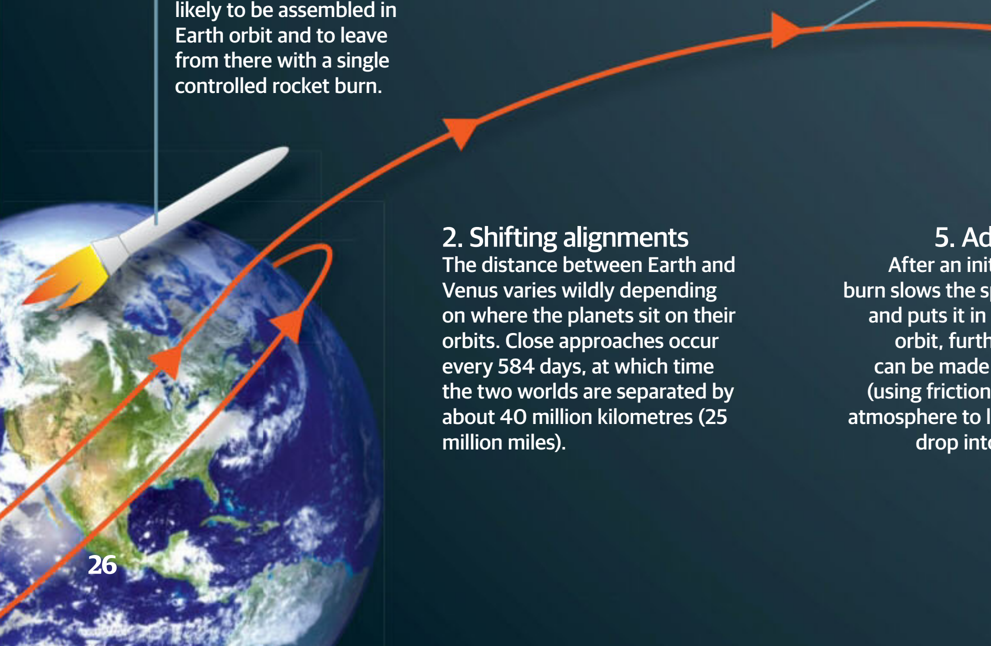
So it might seem reasonable to expect Earth and Venus to have a lot in common - but this is where the similarities end. For centuries astronomers and writers speculated that Venus might have a tropical climate and even alien life - but today, the planet named after the goddess of beauty is often considered 'Earth's evil twin'.

This changed reputation is largely due to the space-age discovery of Venus's scalding-hot, dense and toxic atmosphere. The highly reflective white clouds that shroud the planet boost its brightness as seen from Earth, but their composition - a mix of sulphur dioxide and sulphuric acid droplets - is highly corrosive. What's more, the atmosphere is dominated by carbon dioxide, and its surface pressure is about 93 times greater than that on Earth. The atmosphere traps heat close to the ground, resulting in surface temperatures of around 460 degrees Celsius (860 degrees Fahrenheit) - hotter even than those on Mercury - so any space traveller stepping onto the surface would require a heavily armoured spacesuit to prevent themselves being simultaneously crushed, boiled and choked.

Climate scientists believe that Venus owes its present climate to the disappearance of water early in its history, followed by a runaway greenhouse effect as carbon dioxide built up in the atmosphere. What's more, the absence of water may also be responsible for the fact that Venus lacks tectonic plates like those on Earth, resulting in the extraordinary geology hidden beneath the toxic clouds.



How to get there



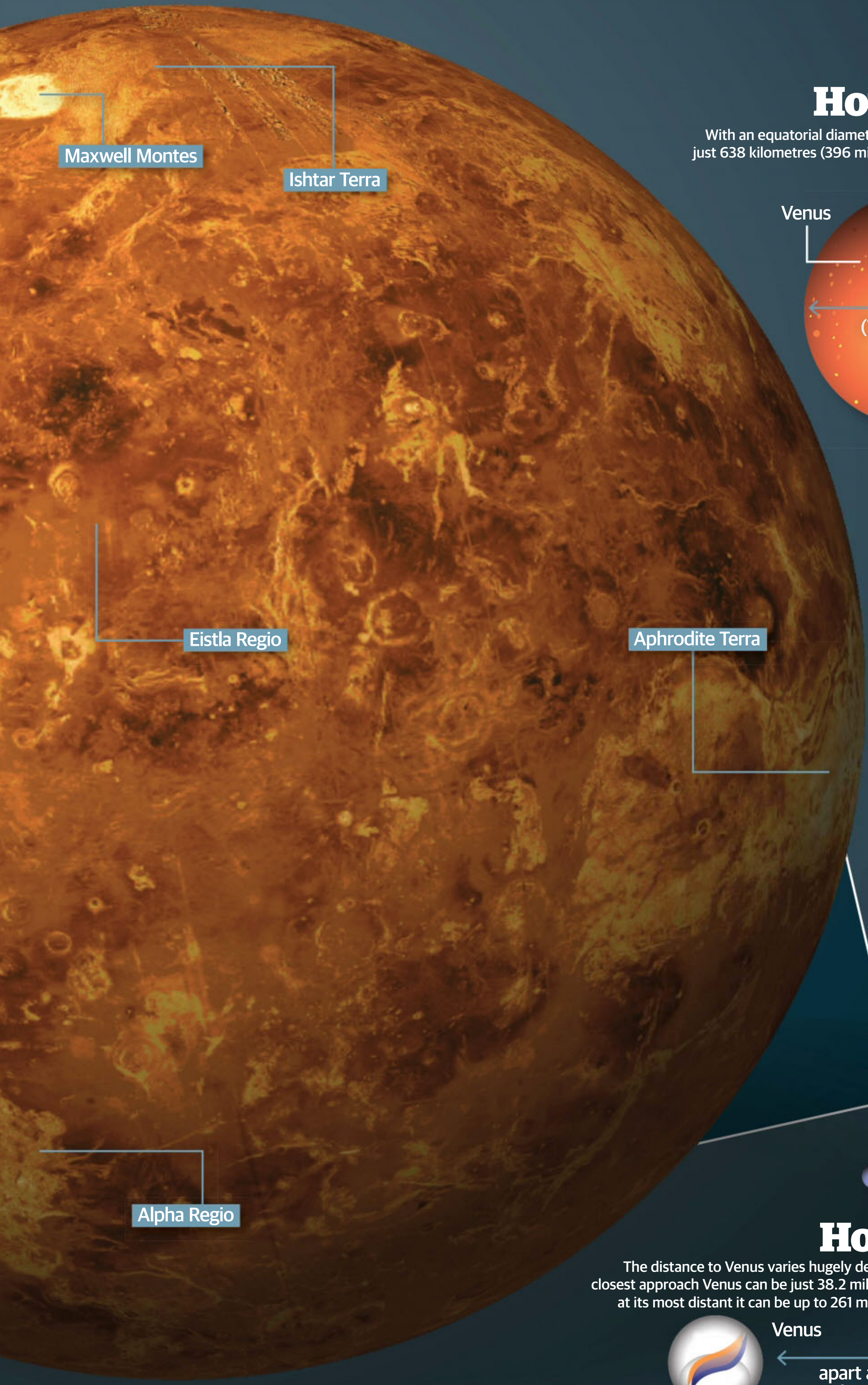
1. Leaving Earth
While a manned Venus mission could theoretically launch direct from Earth, it's more likely to be assembled in Earth orbit and to leave from there with a single controlled rocket burn.

2. Shifting alignments
The distance between Earth and Venus varies wildly depending on where the planets sit on their orbits. Close approaches occur every 584 days, at which time the two worlds are separated by about 40 million kilometres (25 million miles).

3. Towards the Sun
With current technology, it's possible to reach Venus in about four to five months - for the shortest journey along part of a spiral curve, Earth departure would need to take place a couple of months before the date of closest approach.

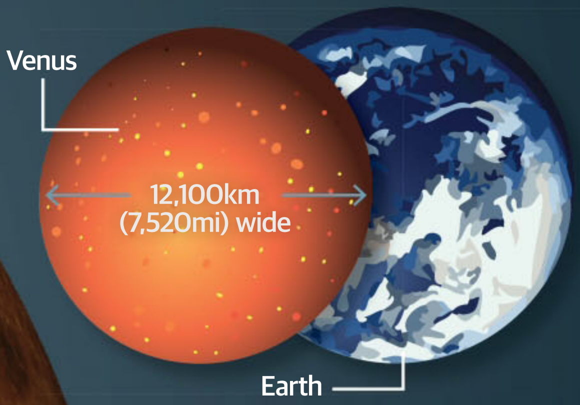
4. Arrival at Venus
Venus moves along its orbit at a speed of 35 kilometres (22 miles) per second - about five kilometres (three miles) per second faster than Earth - but the transfer between orbits and momentum gained during the journey towards the Sun makes it fairly easy to match speeds.

5. Adjusting orbit
After an initial retro-rocket burn slows the spacecraft down and puts it in a wide elliptical orbit, further adjustments can be made by aerobraking (using friction with the upper atmosphere to lose energy and drop into a lower orbit).



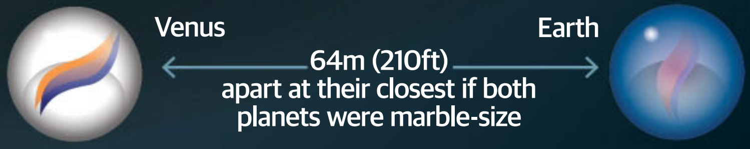
How big is Venus?

With an equatorial diameter of 12,100 kilometres (7,520 miles), Venus is just 638 kilometres (396 miles) smaller than Earth (roughly five per cent).



How far is Venus?

The distance to Venus varies hugely depending on its position relative to Earth. At its closest approach Venus can be just 38.2 million kilometres away (23.7 million miles), while at its most distant it can be up to 261 million kilometres (162 million miles) from Earth.



Top sights to see on Venus

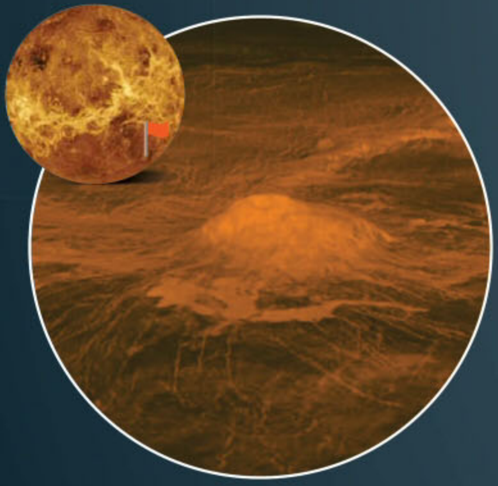
While Earth's surface is shaped by a wide variety of geological forces – such as plate tectonics and erosion, the Venusian landscape is almost entirely shaped by volcanism. Venus is home to a much greater variety of volcanic features than those seen on Earth. The largest, just as on Earth and Mars, are volcanic 'shields' – shallow-sloped mountains formed where lava has erupted through vents in the surface over millions of years, solidifying in layers. However, Venusian shield volcanoes can grow more than ten times larger than those on Earth. This is because Venus's crust seems to be a single mass rather than an Earth-like jigsaw of shifting plates, so volcanic 'hotspots' in the underlying mantle stay in the same place relative to the crust instead of slowly drifting over time. The biggest shields are concentrated in two large highland regions – Aphrodite Terra near the equator, and Ishtar Terra near the north pole.

Rolling lava plains, formed by material erupted from the shields, cover more than half of the surface, while lower-lying areas are relatively smooth, filled in with material slowly eroded by the harsh climate. Stratovolcanoes (the relatively small volcanic cones familiar on Earth) are absent, but there are several uniquely Venusian volcano types – flat-topped 'pancake domes', scallop-edged 'ticks', radiating fissure patterns called 'novae', and web-like 'arachnoids'. Deep, winding chasms, particularly to the south of the equator, look like tectonic rifts found on Earth, but in fact they are faults created as the surface cracked apart due to upward or downward pressure on neighbouring volcanic regions.

Venus's thick atmosphere protects the surface from all but the largest incoming space rocks – as a result the planet has relatively few impact craters. The number and distribution of craters can still be used to estimate the age of different parts of the Venusian surface, however, and reveals that the entire planet was resurfaced in a period of catastrophic volcanism around 500 million years ago. One possible explanation is that while Earth's plate tectonics allow a steady release of heat from the mantle, Venus's solid crust produces a 'pressure cooker' effect in which heat gradually builds up until it finally escapes in a series of worldwide eruptions.

Active volcanoes?

While no one has yet caught a Venusian volcano in the act of eruption, the detection of fresh ash around hot volcanic peaks – such as Idunn Mons shown here – suggests activity in the geologically recent past.

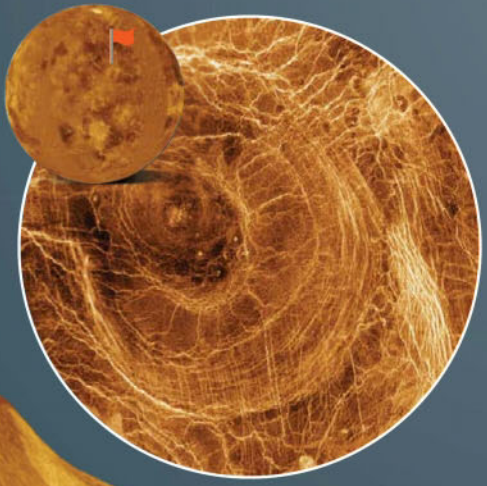


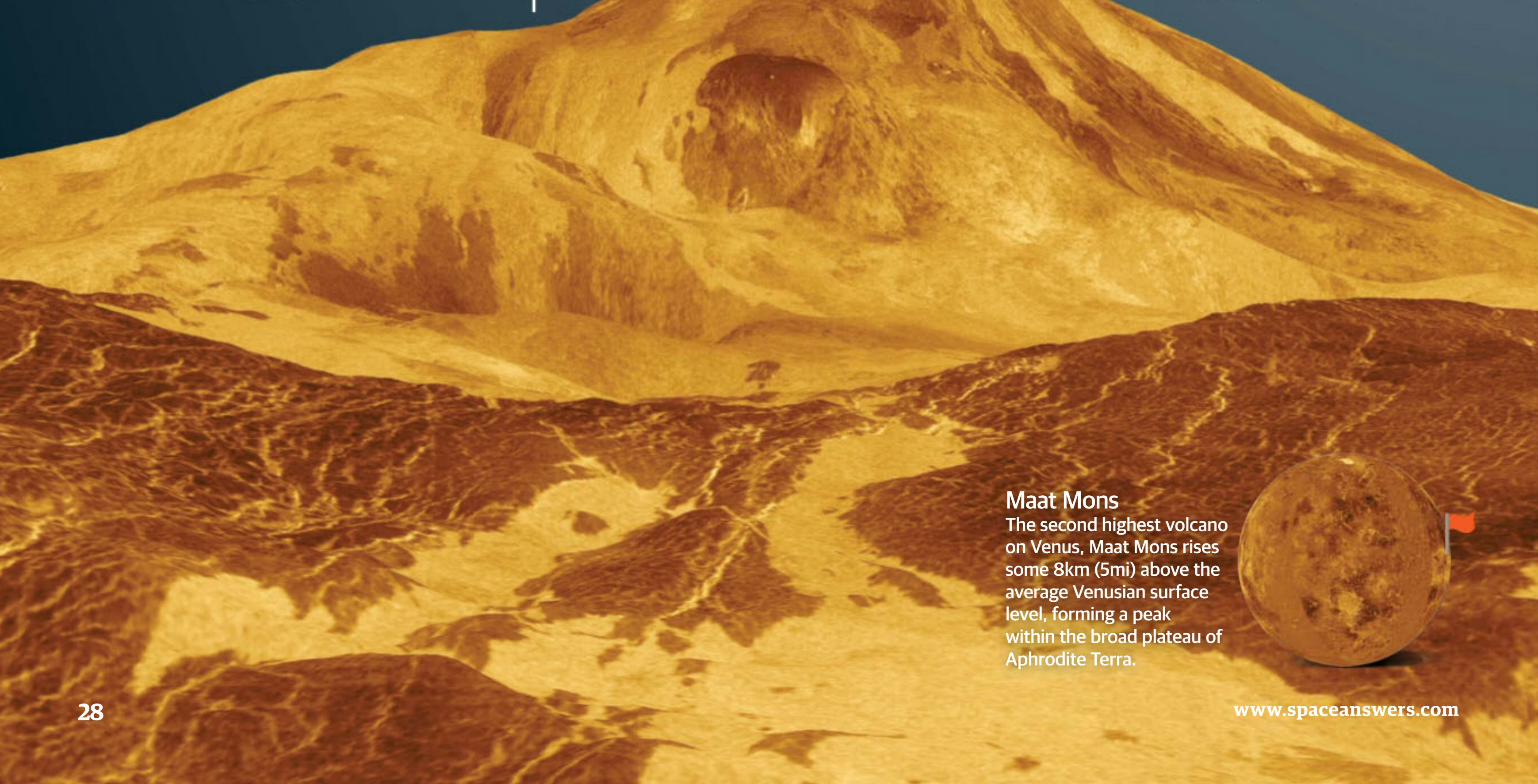
Triple crater

Venus's most spectacular impact feature is the Danilova group – a trio of craters each about 50km (31mi) wide, formed when a single incoming meteoroid broke up in the atmosphere.

Spiders from Venus

Arachnoids combine concentric rings and radiating fractures to form a pattern like a spider's web. They may be created when rising volcanic material pushes the crust upwards, and later subsides.





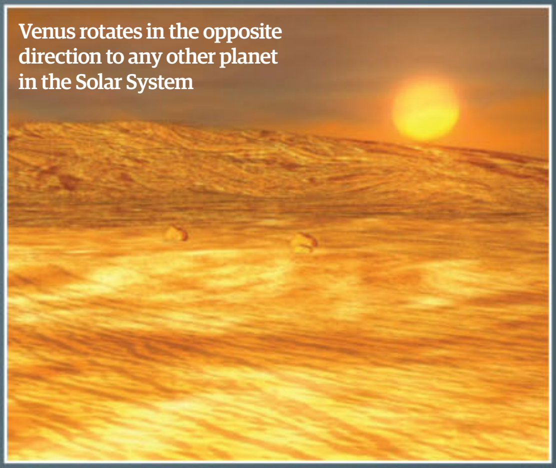
Maat Mons

The second highest volcano on Venus, Maat Mons rises some 8km (5mi) above the average Venusian surface level, forming a peak within the broad plateau of Aphrodite Terra.

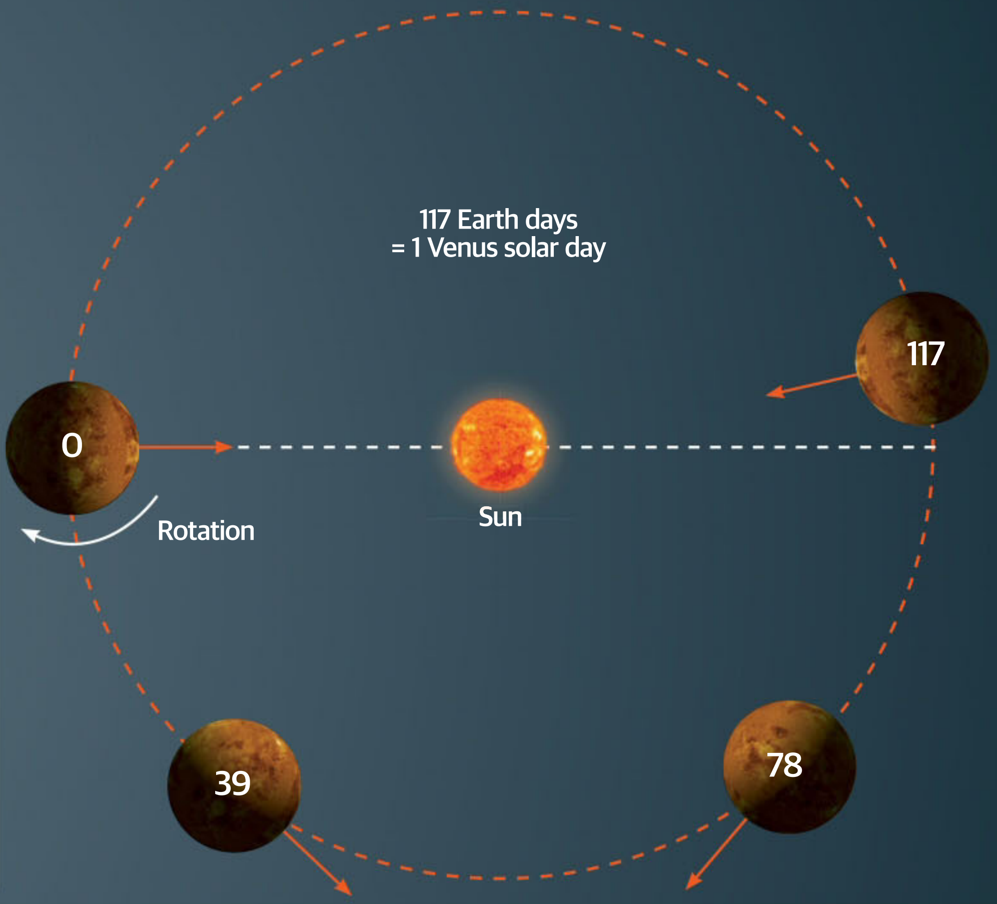
Venus's orbit

Venus orbits the Sun every 224.7 days at an average distance of 108.2 million kilometres (67 million miles). However it spins on its axis every 243.7 Earth days, so its day is significantly longer than its year. What's more, Venus spins in the opposite direction to any other planet, so according to some conventions, its poles are actually upside down relative to the other planets of the Solar System. Because its axis of rotation is almost upright compared to its orbit, Venus lacks any significant seasons.

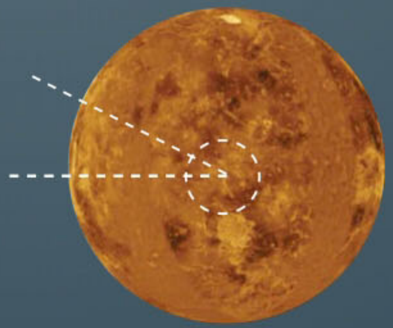
1 Earth year = 365 days
1 Venus year = 224.7 Earth days



Venus rotates in the opposite direction to any other planet in the Solar System



Venus in numbers



224.7

Time taken in Earth days for Venus to orbit the Sun

Weather forecast

464°C
867.2°F

Venus's weather hardly changes due to the oppressive effect of its thick atmosphere and its lack of seasons. Winds at the surface are sluggish, and while the clouds are thought to rain sulphuric acid, this evaporates before it reaches the surface. The planet's slow rotation allows the atmosphere to redistribute heat, making Venus's night side just as hellish as its daylit side. Ultraviolet images reveal huge chevron-shaped cloud features moving slowly in the upper atmosphere.

2.64°

Tilt of Venus's axis of rotation relative to the plane of its orbit

0.905

Strength of Venus's surface gravity relative to Earth's

96.5%

Percentage of carbon dioxide in Venus's atmosphere (compared to Earth's 0.04%)

464°

Average surface temperature in Celsius – hotter than Mercury

243

Venus's rotation period in Earth days – longer than its year

1.92

Length of a year on Venus in terms of its 'solar day' – the time between successive sunrises

© Freepik.com; NASA

How to build a ROCKET

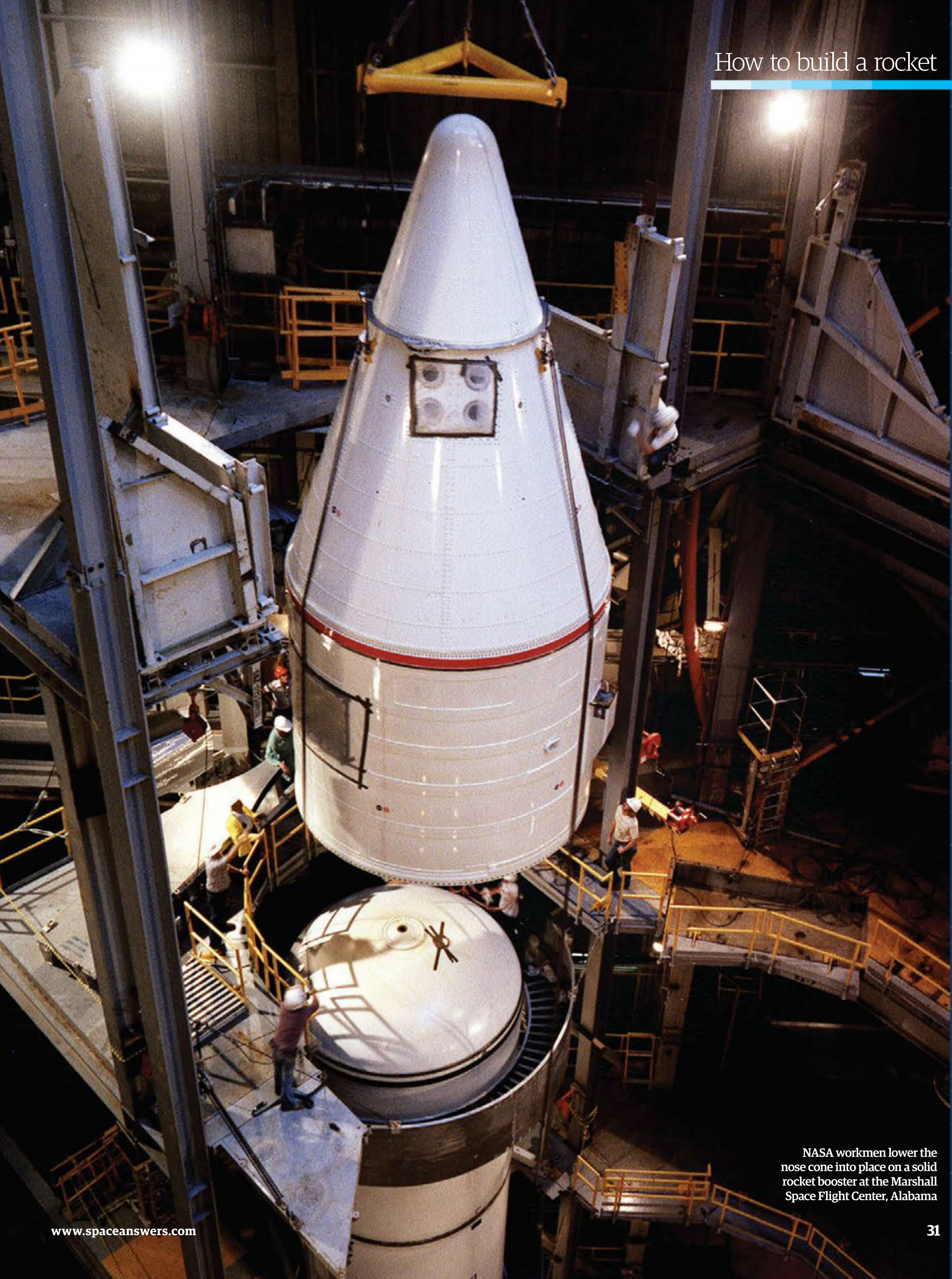
From concept to launch, the life cycle of a modern rocket is a fascinating journey that involves hundreds of engineers and billions of dollars

Written by Dominic Reseigh-Lincoln

From their humble origins in the Chinese invention of gunpowder and fireworks in 700 CE to the towering behemoths that hurtle astronauts and satellites alike into space, the rocket remains the centrepiece of modern space travel. Whether they're models designed and used by the biggest space agencies in the world, or those constructed in the private sector to deliver parts and supplies to sites such as the International Space Station, the genesis and eventual launch of a rocket takes the involvement of hundreds of engineers and years of careful planning.

So where does it all begin? The main foundations of a rocket's life can be broken up into a handful of key phases: formulation, detailed design, and manufacturing and operations. During the formulation phase, the broad brushstrokes of the architecture and development plans are put in place. As part of making these decisions, a large number of potential concepts and variations are considered by multiple teams working in unison. "The conceptual studies on heavy-lift systems have been going on at a low level for decades in support of various initiatives," says Tyler Nester, an associate chief engineer working on NASA's hotly anticipated new Space Launch System (SLS). "The conceptual studies that helped shape SLS started in earnest in the 2011 time period, so there are a number of people that are involved in an effort like designing, developing and operating SLS as the programme evolves."

Early in the design of a new rocket, the emphasis is firmly on conceptual ideas. During this phase



NASA workmen lower the nose cone into place on a solid rocket booster at the Marshall Space Flight Center, Alabama of pre-production, programmes typically need a lower level of staffing. The detail of the design and analysis work increases as the number of concepts under study gets narrowed down to a smaller figure. "The number of people that need to be involved can vary depending on the planned flight rate," reveals Nester. "As programmes transition between phases, people's jobs tend to evolve based on what is needed during that phase. The current plans show a desired first flight date a little less than seven years after the [Space Launch System] programme started in 2011."

At this stage an important decision has to be made regarding a rocket's future: will it aim to operate as a reusable vehicle (where its components are directed back into the sea or onto specialised platforms) or will it aim for the more traditional one-use system (where a rocket's many parts are usually lost in re-entry or left to drift in space). Such a decision was a key point of discussion at the earliest formulation stages of the SLS programme, but in the end like many other rocket programmes operated by NASA and the ESA, the expendable route was chosen.

But what's the rationale behind such a decision? Interestingly, the most obvious factor of cost isn't as one-sided as you might think. "The decision on expendable versus reusable hinges on how reusability impacts performance, cost and reliability," says Nester. "For the cost piece of the puzzle, the recurring, non-recurring, fixed and variable portions of the cost need to be considered. Reusability is a great concept, and the Shuttle programme realised some cost savings via reusability.

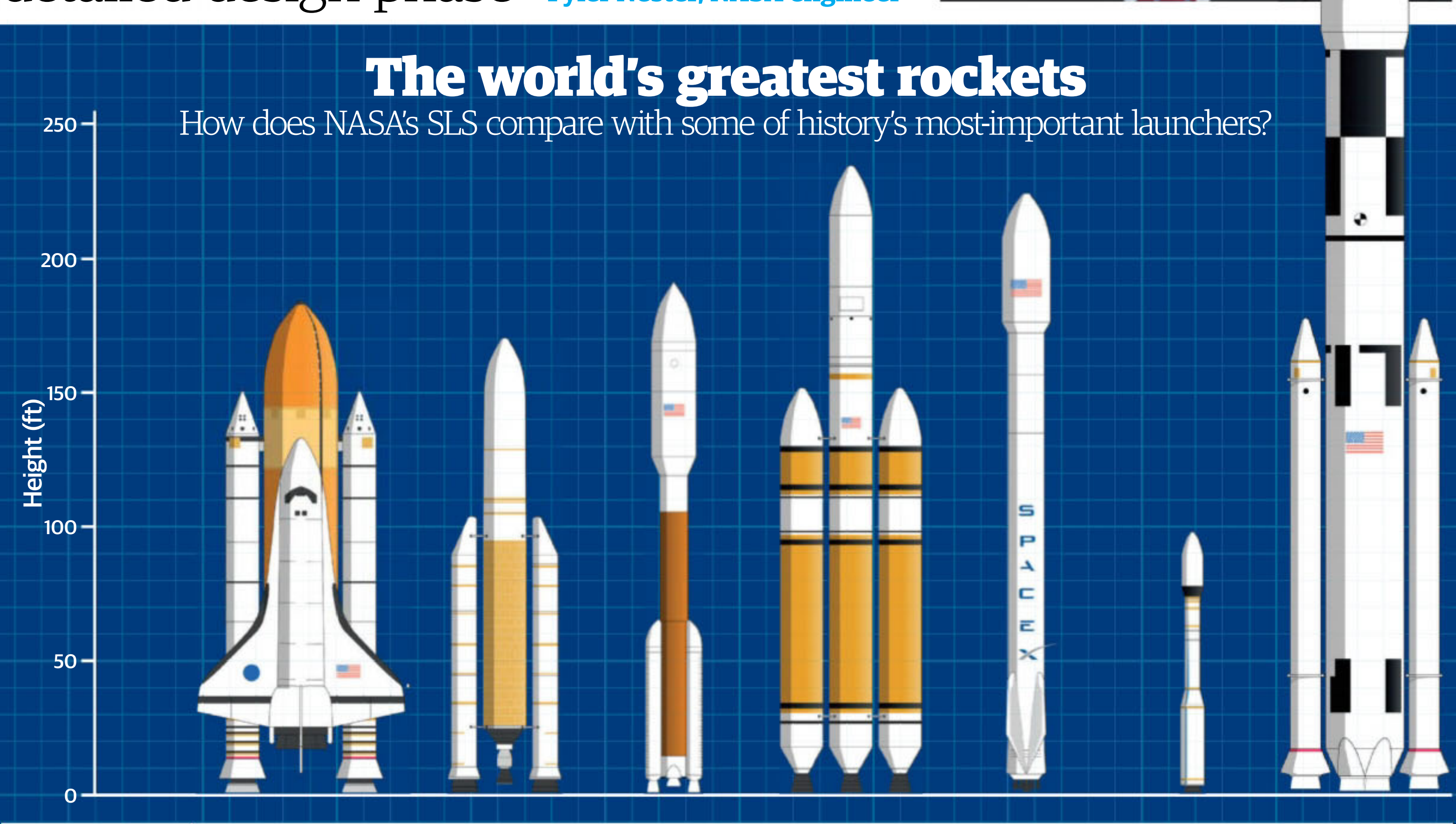
"For SLS, even though some of the hardware is the same hardware as the Shuttle, the differences in flight rate and application are such that reusing these components was predicted to result in an increase in programme cost (as opposed to generating a savings on the Shuttle programme). For our application, the balance of considerations showed that the 'costs' of reuse weren't justified by the benefits," he adds.

Now that the main elements of the rocket's design have been formulated, a more detailed design is

> "For programmes like SLS, the designs solidify as they progress through the detailed design phase" **Tyler Nester, NASA engineer**

The world's greatest rockets

How does NASA's SLS compare with some of history's most-important launchers?



Name	Space Shuttle	Ariane 5	Atlas V	Delta IV Heavy	Falcon 9	Vega	SLS
Years of operation	1981-2011	1996-2009	2002-present	2002-present	2010-present	2012-present	From 2018
Height (ft)	184	171	191	235	224	98	384
Fuel type	Solid	LOX/LH2	RP-1/LOX	LH2/LOX	LOX/RP-1	HTPB (Solid)	LH2/LOX
Thrust (lbf)	1,180,000	310,000	933,000	710,000	1,700,000	508,300	1,670,000
Payload to LEO (tn)	24.4	21	18.5	29	13	1.4	130
Used for	Satellites, probes and manned missions	Satellites	Satellites	Satellites	Satellites	Satellites	Manned missions
Destinations	Hubble Space Telescope, International Space Station	Geostationary transfer orbit and long term orbit	Low-Earth orbit, geostationary transfer orbit	Low-Earth and Sun-synchronous orbit	Low-Earth orbit	Low-Earth, Sun-synchronous and polar orbits	Beyond low-Earth orbit, asteroids, Mars

needed. NASA's Space Launch Project, unlike almost any other modern rocket programme, makes this specific design process even more complicated. The plan is to split the rocket's programme into three separate phases known as 'blocks'. These phases 'Block 1', 'Block 1B' and 'Block 2' are all based on the same central core and set of four rockets, but each one has unique characteristics that will define each stage of the programme's post-launch life cycle.

For instance, the second phase 1B will employ a more powerful second segment known as an Exploration Upper Stage that will aim to take teams of human astronauts farther into space than ever before, most notably those that will man NASA's Orion spacecraft. The decision to design three iterations of the same rocket may seem a strange one, but it's emblematic of the desire to take manned missions beyond the Moon.

"For programmes like SLS, the designs solidify as they progress through the detailed design phase," says Nester on whether these designs are set in stone from the start or shift as new developments are made. "Based on when the system's blocks are projected to be needed, the different blocks are at different phases in the typical programme life cycle. For each block, we assess the potential implications on the parts that will be common across the blocks. For the evolutions that could occur in the nearer term, more and more of the details are being finalised each day. These details will all be finalised as we get closer to manufacturing the different elements of the evolved configurations."

In many cases, a rocket's design will often draw upon certain characteristics from previous programmes. And while this practice is there to ensure the advances made elsewhere are retained and refined upon, it's also a vital way to keep costs from spiralling out of control. In some cases it's not just the amalgamation of previous developments, but the inclusion of actual components from cancelled or retired projects. Since a new rocket programme is often designed as much for its cost effectiveness in comparison to current launch programmes as it is the potential scientific possibilities, using existing parts has become commonplace.

A total of 16 RS-25 engines from the defunct Space Shuttle programme have been incorporated into the SLS's design (15 of which have been used in previous Shuttle missions). Elsewhere, a majority of the metal hardware used for the programme's five-segment rocket boosters were also used on the Shuttles, whereas the interim cryogenic propulsion system (which will be located in the Upper Stage of the rocket, propelling the Orion spacecraft above it) has been incorporated from the Delta IV rocket (a vehicle still in use today). In fact, the SLS has even integrated the booster avionics, engine controller and core stage systems from the Ares programme. It's a common practice in both national space agencies and private manufacturers such as SpaceX and one that's driven rocket design since the earliest iterations.

It's now that a rocket enters the manufacturing and operations stage of its life cycle. The definitive blueprints for the rocket are now sacrosanct, detailed down to the last bolt, cut and wire. Everything from materials required to the amount of man hours needed to construct, test and eventually launch

Engineers oversee the welding of a liquid hydrogen fuel tank for an Ariane 5 rocket in Les Mureaux, France

The Soyuz TMA-16M spacecraft being assembled at Baikonur Cosmodrome, Kazakhstan on 24 March 2015. Four days later it would take the Expedition 43 crew to the International Space Station the rocket are determined years in advance so construction of its composite parts can begin. And for Nester and the rest of the team working on the SLS, learning from past projects is key to building the composite parts of a rocket. "We are using a lot of lessons learned from previous programmes in our efforts to streamline the development and manufacturing processes. For example, in many areas, we have applied lessons from lean manufacturing to improve our manufacturing operations and reduce our manufacturing costs."

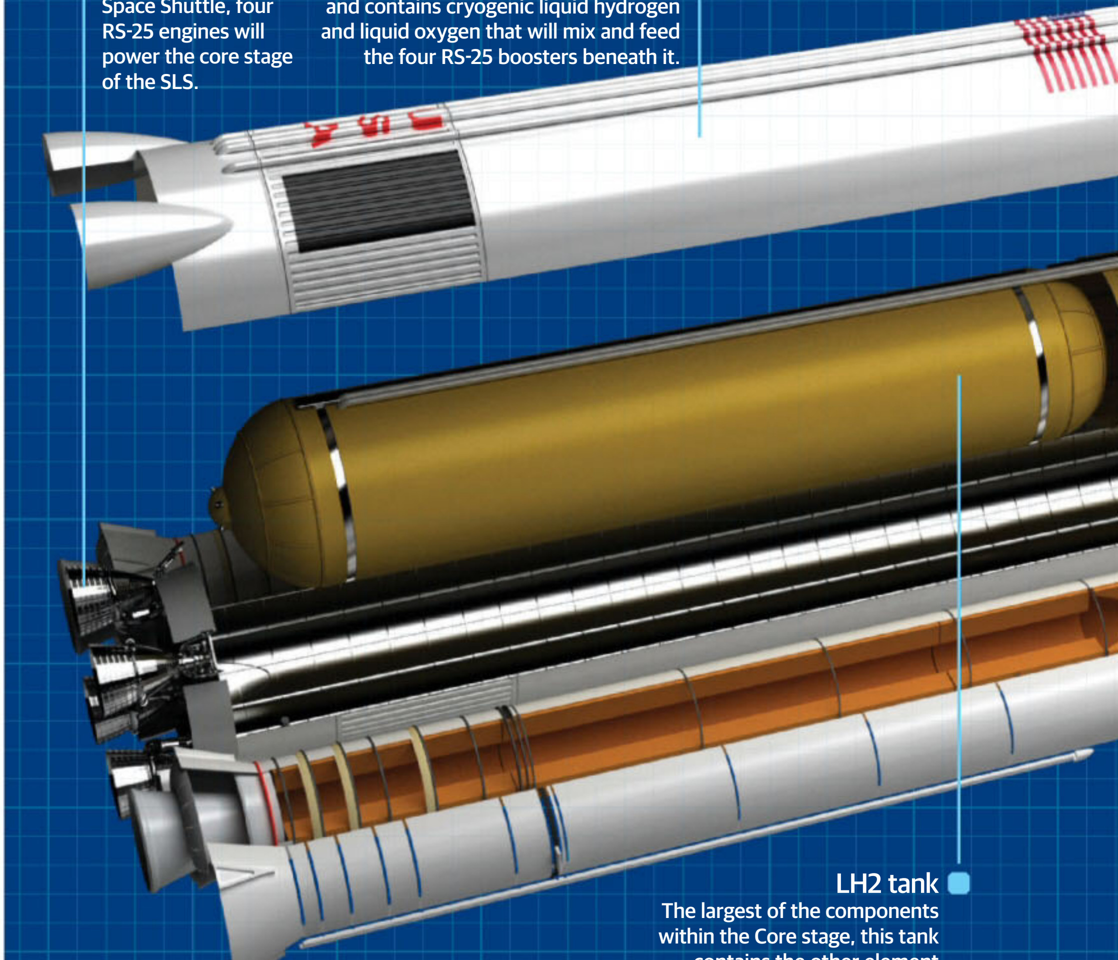
In some cases, rockets are built and tested in different locations, with multiple teams assembling payload constructs while others test and refine boosters. For projects on the magnitude of the Space Launch System, every facet of the rocket is being constructed and rigorously tested on one huge site, namely the Michoud Assembly Facility in New Orleans, Louisiana. The facility itself is one of the largest of its kind in the world, with a staggering 17 hectares (43 acres) housed under one roof. It's so big in fact, engineers such as Nester have to use bicycles just to reach different divisions.

And many of those divisions are now using new advancements (and enduring procedures) to create the most resilient and affordable materials for everything from the rocket's outer shell to its internal circuitry. "One of the most important considerations is understanding the environments in which the system will need to operate and designing the system to operate in those environments," explains Nester. "This is true for the ascent phase portions of the mission and for the in-space portions of the mission. The analytical and testing tools that are being used are critical to making this process work. The advances in computer-aided design (CAD) and computer-aided engineering (CAE) technology has been a key enabler to enabling us to design and analyse the system."

According to Nester, the new elements of the system are being designed to take advantage of developing manufacturing technologies (such as new joining/assembly innovations, additive manufacturing etc) as well as the use of 3D printing, as "the combination of new design technologies and the new manufacturing technologies enables us to consider things that were previously not possible."

Building the SLS

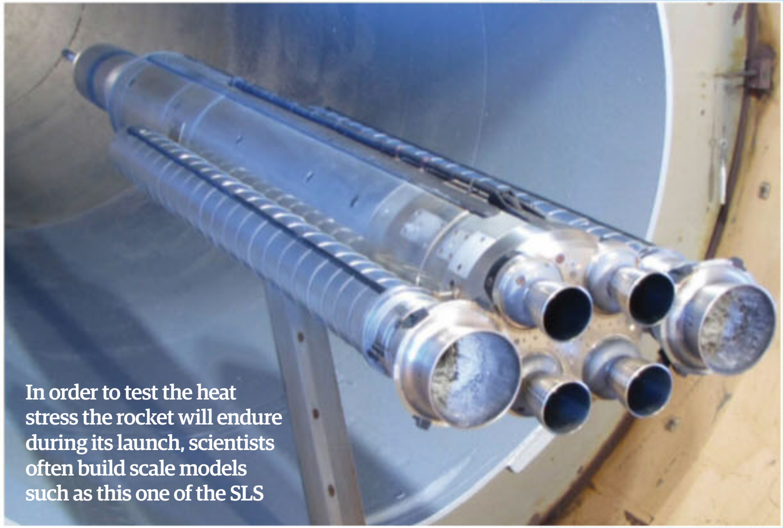
What makes the Space Launch System the most powerful rocket ever made?



RS-25 engines
Previously used as the main engine of the Space Shuttle, four RS-25 engines will power the core stage of the SLS.

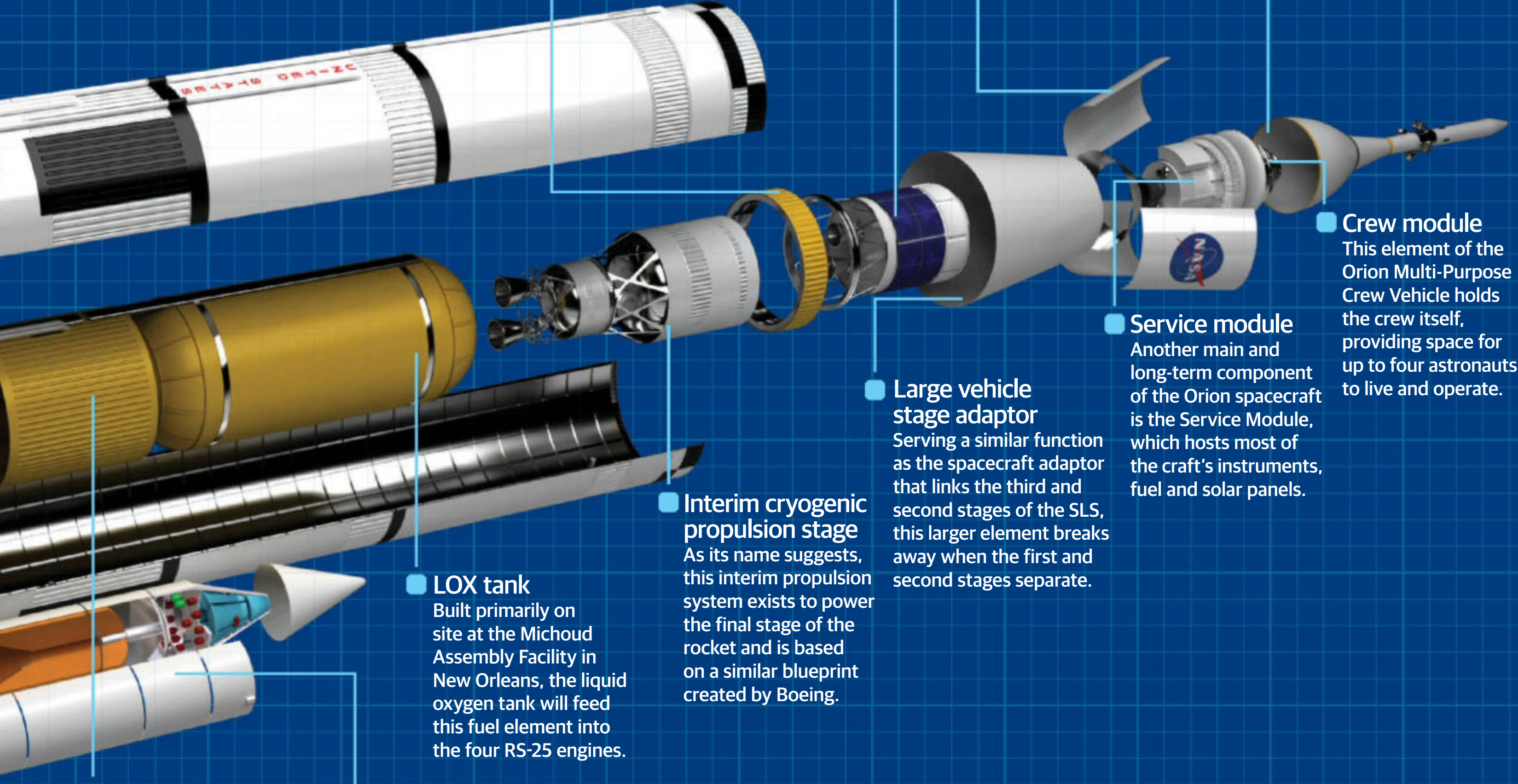
Core stage
The first and largest element of the SLS, the core stage is 61m (200ft) tall and contains cryogenic liquid hydrogen and liquid oxygen that will mix and feed the four RS-25 boosters beneath it.

LH2 tank
The largest of the components within the Core stage, this tank contains the other element needed to fuel the RS-25 rockets below – cryogenic liquid hydrogen.



In order to test the heat stress the rocket will endure during its launch, scientists often build scale models such as this one of the SLS

The Orion spacecraft, seen here being moved in preparation for a testing simulation, is one of the highest profile payloads on the SLS's schedule



Forward skirt
Built by ATK in Promontory, Utah, this element connects the Core stage of the rocket with its twin rocket boosters on either side.

Spacecraft adaptor
The final element of the Orion spacecraft, the spacecraft adaptor is designed to create an airtight lock between the craft and the remainder of the rocket.

Encapsulated service module panels
These panels, comprised mainly of reinforced fibreglass, are jettisoned once the final stage of the rocket's launch is initiated.

Launch abort system
Built purely for emergencies during launch, the escape rocket is there to propel a manned crew to safety in the early stages of launch.

Crew module
This element of the Orion Multi-Purpose Crew Vehicle holds the crew itself, providing space for up to four astronauts to live and operate.

Service module
Another main and long-term component of the Orion spacecraft is the Service Module, which hosts most of the craft's instruments, fuel and solar panels.

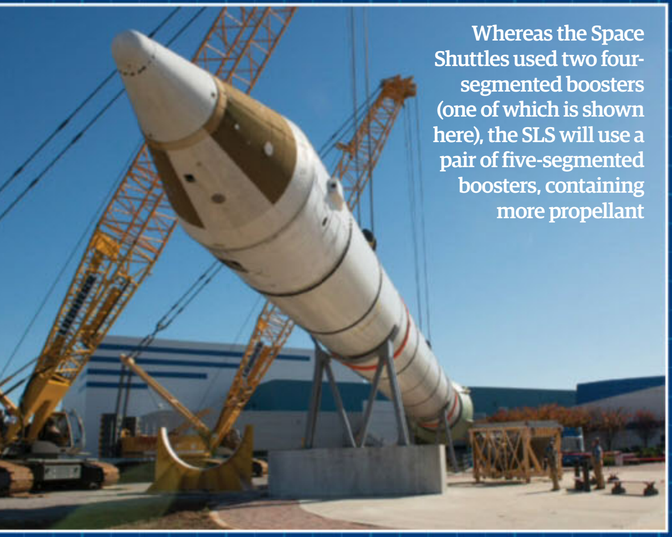
Large vehicle stage adaptor
Serving a similar function as the spacecraft adaptor that links the third and second stages of the SLS, this larger element breaks away when the first and second stages separate.

Interim cryogenic propulsion stage
As its name suggests, this interim propulsion system exists to power the final stage of the rocket and is based on a similar blueprint created by Boeing.

LOX tank
Built primarily on site at the Michoud Assembly Facility in New Orleans, the liquid oxygen tank will feed this fuel element into the four RS-25 engines.

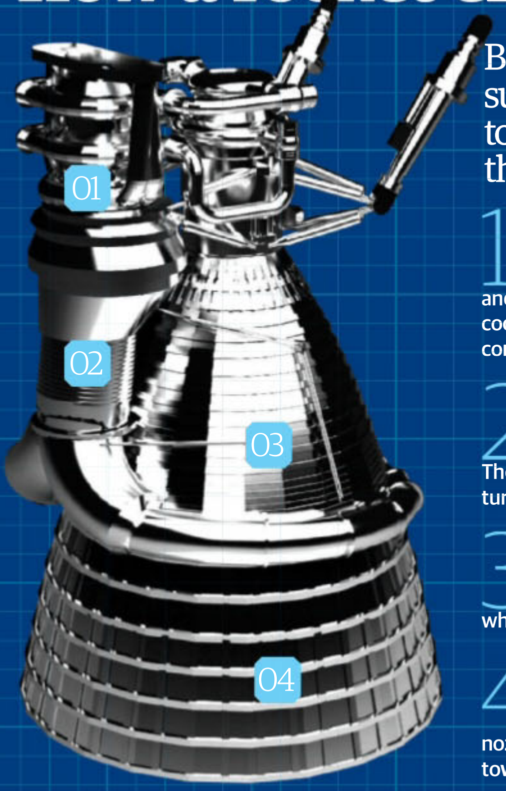
Intertank
One of a number of components incorporated from the defunct Space Shuttle programme, the intertank feeds fuel loads between the LOX and LH2 tanks.

Solid rocket boosters
The Space Launch System will be using two separate boosters to power its launch into the Earth's upper atmosphere, contributing to its 70-metric-ton capability.



Whereas the Space Shuttles used two four-segmented boosters (one of which is shown here), the SLS will use a pair of five-segmented boosters, containing more propellant

How a rocket engine works



Before launch, boosters such as those that belong to the Saturn V, must go through several stages

1 Getting pumped
Keeping the weight of a rocket to a minimum is vital to getting it in the air. To do this, the fuel and oxygen propellants are liquified with extreme cooling. The pumps begin by sending these to the combustion chamber.

2 Fuel injection
On its way to the turbo pump, the fuel is then syphoned through coolant passages. The newly pressurised fuel then passed over the turbine, causing it to rotate.

3 Fired up
The fuel and oxidiser components are pumped into the combustion chamber proper where they're superheated into a high-pressure gas.

4 Chain reaction
As the gas is squeezed through the throat of the combustion chamber and out of the nozzle it creates thrust, which pushes back up towards the chamber lifting the rocket.

New advancements in manufacturing, such as NASA's 51.8m (170ft) tall Vertical Assembly Center, have helped build rockets faster and safer

SpaceX currently uses its Falcon 9 rocket, along with the Dragon capsule, to resupply the International Space Station

Boosters, such as this one being prepped for a test at Orbital ATK's facility in Utah, are rigorously tested throughout production

Modern rockets capable of carrying everything from supplies to a manned mission are composed of multiple 'stages' that are designed to systematically power a given payload out of the Earth's atmosphere and towards a designated region of space/point of orbit. The lower stage is the largest, containing the biggest thrusters and thousands of litres of fuel (types of fuel differ, but most use a mixture of liquid oxygen and kerosene) it is designed to produce a gargantuan amount of thrust in order to lift a rocket off the ground and into our atmosphere.

For rockets designed to carry multiple types of payload over its life cycle, ensuring the lower stage is capable of lifting the varying weight (and the forces this generates) is a key factor for consideration. "Depending on the needs of a particular payload, we may change the fuel loading to optimise for a specific case," adds Nester. "In some cases, options for adding small amounts of propulsive capability as part of the payload are possible. The different 'blocks' realise increased capability by incorporating groups of upgrades as a 'block' changes."

Many rockets, including the Delta IV rocket are composed of one additional segment, with the second stage (or Upper Stage) constructed of additional boosters, a structural shell and the payload itself within (these are mostly used to send satellites into orbit and are far easier and inexpensive to build/launch). For larger and more ambitious projects such as the SLS, a special three-part setup has been used. While the factor of cost will always temper the fires of innovation to a degree, many scientists and engineers working in the field believe three-stage rockets such as the Space Launch System are key to taking manned missions beyond the Moon and into the Solar System proper.

And so, after years of research, testing and manufacturing, the multiple stages of a rocket are constructed and the rocket itself is prepared for launch. Launch sites such as NASA's Kennedy Space Center in Florida and the European Space Agency's Guiana Space Centre in French Guiana house multiple platforms that can be customised to meet the dimensions of a given vehicle, although private manufacturers such as SpaceX have been testing the feasibility of sea-based launch platforms.

For something as monolithic as the SLS, NASA engineers had to go as far as building a brand-new one in preparation. "Our partners in the Ground Systems Development and Operations (GSDO) project at KSC are putting in place the facilities to assemble and launch SLS," adds Nester on the subject. "They are basing their designs and plans on a careful study of best practices from across the industry." Launches themselves take years of planning, but are often the swiftest phases of the rocket's life cycle thanks to rigorous test flight initiatives.

So far in 2015, 55 rocket launches have been conducted across the globe. Of these 55, 52 were successes (with two major failures and one partial failure). Thankfully, the rate of astronaut fatalities caused by malfunctioning rockets has steadily reduced as advances in safety measures take hold. Projects such as the Space Launch System, and others such as the Vega, Ariane and Atlas rockets are ushering in a new era of spaceflight as man reaches further and further into the heavens. ■

> "We're using a lot of lessons learned from previous programmes to streamline development and manufacturing" **Tyler Nester**

@ Alex Pang; Ed Crooks; ESA; NASA; SPL; Alamy

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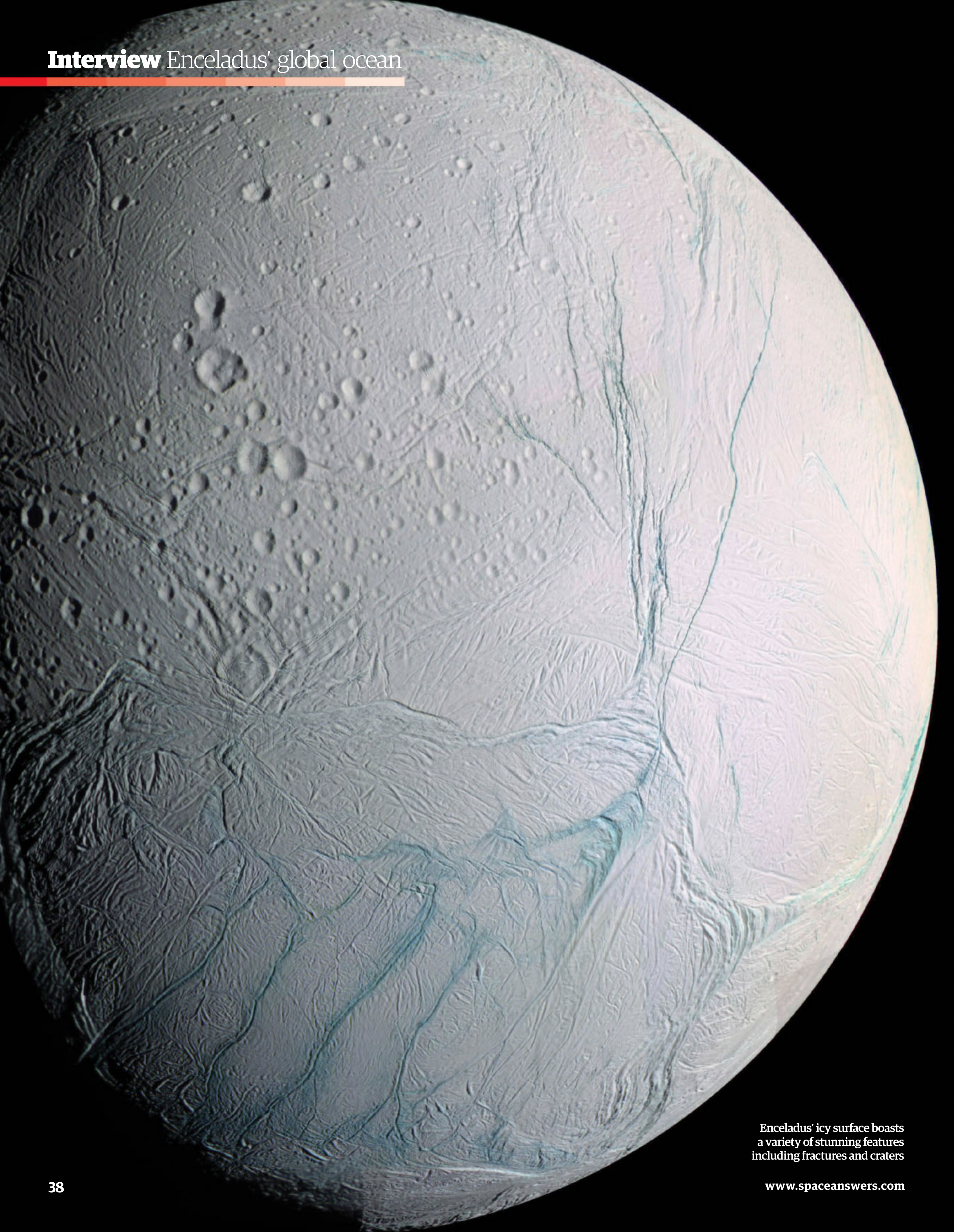


Enceladus' icy surface boasts a variety of stunning features including fractures and craters

Enceladus' global ocean

Last month, we received concrete evidence that the Saturn moon hosts a vast expanse of water under its crust. **All About Space** caught up with Carolyn Porco of NASA's Cassini mission to find out more

Interviewed by Gemma Lavender

After we discovered the geysers on Enceladus, why did it take all of this time to find their source?
Other than to look for plumes coming off Enceladus, which we first saw in February 2005 in a set of images designed to look for [these ejections], we had no other plans in the nominal four-year mission for specific observations of geysering activity. How could we? We weren't sure [the ocean] existed. So once we found them, we altered the nominal mission as much as we could to get a closer look and, of course, we designed many observations in the extended mission to develop a much more complete picture about the phenomenon. This included a set of flybys to measure the mass distribution within the outer layers of the moon in the south polar region, as well as very high-resolution images of the geyser field and Enceladus' surface.

It wasn't until 2013, at which point the gravity results were adequately analysed, that we had confirmation of a liquid layer about ten kilometres (6.21 miles) thick under the south polar terrain. We realised that it was at least as wide as the south pole region, but a global ocean couldn't be ruled out. Under certain reasonable assumptions, some analyses suggested it should be global. But that conclusion didn't carry a high degree of confidence.

As we saw, it wasn't until last month that my team members finally finished their work utilising our

Porco leads the imaging team of NASA's Cassini mission

INTERVIEW BIO

Carolyn Porco

Carolyn Porco is an American planetary scientist who leads the imaging science team on the Cassini mission, currently in orbit around Saturn. She's the founder of The Day the Earth Smiled, which took place in 2013 when Cassini imaged Saturn, its entire ring system, and the Earth during an eclipse of the Sun. Porco is also an imaging scientist on the New Horizons mission. She has won a number of awards and honours for her contributions to science including the Carl Sagan Medal and was named one of the 25 most influential people in space by *Time* magazine in 2012.

high-resolution images of the surface. We managed to tease out a small wobble in the rotation of Enceladus that is best explained by a global ocean.

These analyses are all, at this stage in the mission, very sophisticated, requiring more than just a look/see engagement with an image, but a lot of work. And good, careful work takes time.

Could you tell us a bit more about the techniques used to find the ocean?

The first confirmation that there was a liquid layer about 35 kilometres (21.75 miles) below the south polar terrain came from the gravity signature. The distribution of mass under the south polar terrain was detectable by carefully tracking the motion of the Cassini spacecraft as it flew closely over Enceladus' south pole. Doing three such flybys allowed the gravity team to figure out that the water layer had to be about 35 kilometres (21.75 miles) beneath the surface and about ten kilometres (6.21 miles) thick.

The confirmation that the ocean is global came from noticing how the rotation of Enceladus was not uniform but sometimes slightly faster and sometimes slightly slower. To do this, my team members were using features on the surface as benchmarks - kind of like painting a white stripe on your car tyre - and comparing the positions of the features at various times to see how they compared to where they would have been if there were no wobble.

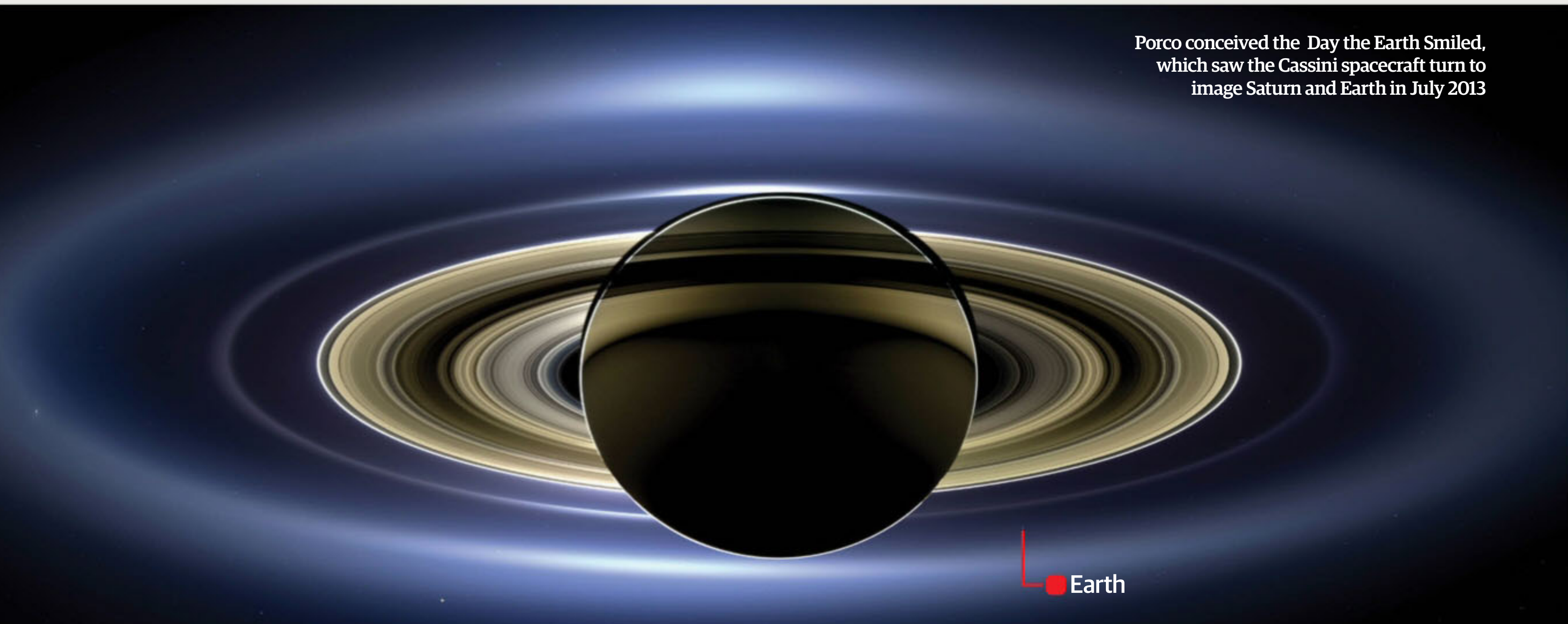
And the magnitude of the wobble indicates something about the interior - in particular, whether the ice shell moves independently of the core or is attached to it. In this particular case, they found that the ice shell has to be moving independently and that can only be the case if it is floating on a liquid layer.

What do you think the ocean is likely to be made up of?

We know from those instruments on Cassini that have sampled the Enceladus plume that the source of

Cassini is the first spacecraft to enter into orbit around Saturn and is currently studying the gas giant and its moons

> "We managed to tease out a small wobble in the rotation of Enceladus that is best explained by a global ocean"



Porco conceived the Day the Earth Smiled, which saw the Cassini spacecraft turn to image Saturn and Earth in July 2013 the ocean is mostly water, with trace amounts of salt and organic compounds.

Does the confirmation of an ocean make Enceladus an additional target for life?
Once we knew Enceladus had any liquid at all, but especially that it's liquid is in contact with a core, we knew it was a target for searching for extraterrestrial biology. So we've known that for quite a while and for about ten years. This new observation, however, makes the story richer, and may tell us that there is more energy being injected into Enceladus over the course of time than we had previously thought. So if it does anything, it may mean that any living organisms there may have had a longer time to evolve than we originally suspected. Maybe when we get back there to look closely, instead of finding micro-organisms, we'll find lobster and sushi!

If you could hazard a guess, what do you think life on Enceladus would be like?
It's fair to say we all have micro-organisms on the brain. I'd fall off my chair, assuming I'm still able to sit on chairs when the time comes, if there were anything as complex as shrimp or sea horses. [If that were the case] wow, that would be a stunner.

Similarly, we're interested in Jupiter's moon Europa for its oceans. Is there now going to be difficulty in deciding which moon we should send a mission to first?
In my mind, Enceladus was the clear winner if the goal was to sample an extraterrestrial habitable zone – a candidate environment for life – as soon and as easily as possible. Why? The operative word with Enceladus is accessibility. You don't have to land, scratch, drill or bunker your spacecraft in lead [to protect it from radiation] in order to search for evidence of life. However, other factors like political and technical momentum won and a mission to Europa was chosen and is now under way. So I say: great! Now that we have that mission out the door, the next one in line needs to go to Enceladus. A lot of curious minds want to know if there are microbes snowing at the south pole on that lovely little ice ball.

Would a mission to Enceladus be similar to the Europa Clipper?
The next mission, the Europa Clipper, will essentially bring our knowledge of Europa up to the same level as that of Enceladus, which we have been studying closely now for 11 years. We need to complete the mapping of [Europa's] surface in visible and near-infrared wavelengths to see if there is any thermal emission coming from the surface among other things – all of the things we've already done at Enceladus with Cassini.

If Europa has plumes, the Clipper will carry instrumentation to sample them, though at the moment it seems there are no plumes so it's now not clear how effective that will be.

A group of us have planned a small Discovery-class mission to return to Enceladus. We aim to do one thing and one thing only: fly through the plume repeatedly with only a few instruments to collect samples and look for chemical evidence of life. If that mission is chosen, that's what the next mission to Enceladus will look like. Assuming we haven't found the place to be as dead as a door, the only thing that makes sense would be a more sophisticated mission to do both in-situ sampling and to return a sample to Earth. I hope I live to see the day! ■

(Above) Carolyn Porco and the Cassini Imaging Team; (Below) An artist's impression of Cassini flying through Enceladus' geysers, which were discovered by the spacecraft in the moon's south polar region in 2005

Porco believes its liquid ocean should make Enceladus a leading contender in the search for extraterrestrial life

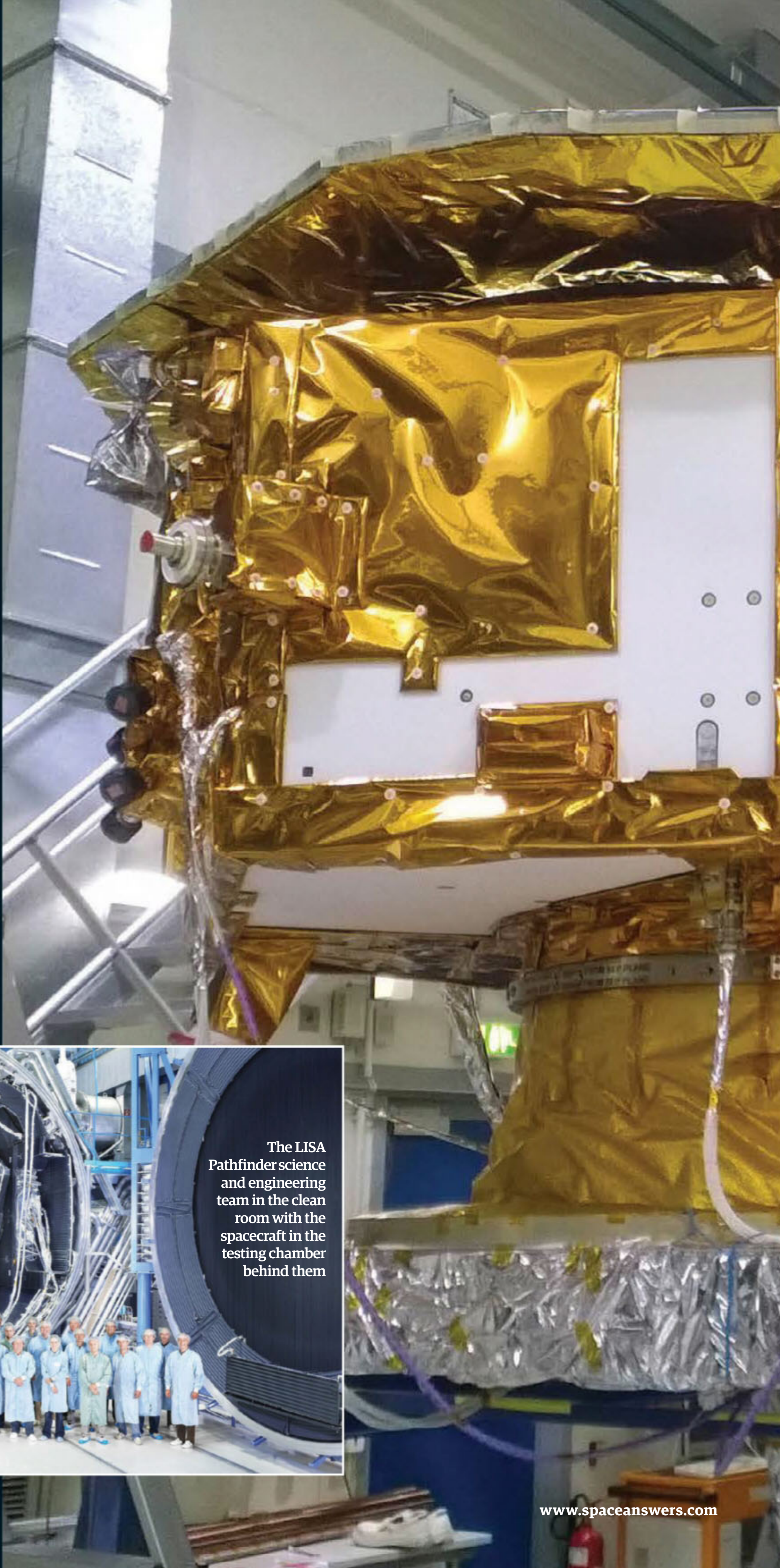
© JPL; NASA

LISA Pathfinder prepares for launch

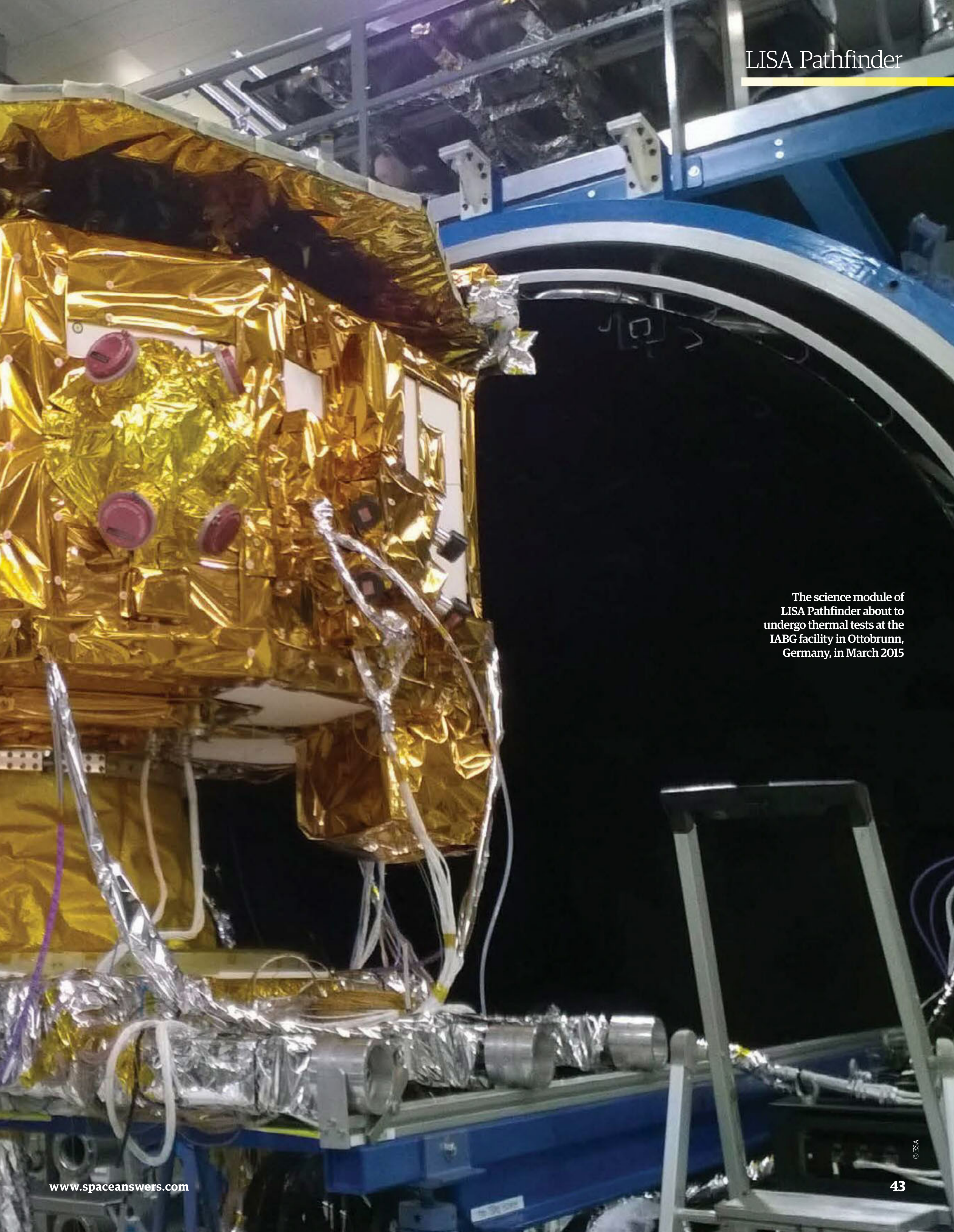
With less than two months until launch, the revolutionary spacecraft takes its final exams

The first part of one of the most precise space missions ever planned is set to launch this autumn to put to the test technology designed to find elusive gravitational waves, which are ripples in the fabric of space-time that come from colliding black holes and neutron stars. The mission, named LISA Pathfinder, is a prototype that will pave the way for the full LISA, or Laser Interferometer Space Antenna, mission next decade. We can see the Pathfinder here undergoing testing at a European Space Agency centre in Germany.

The plan for the full LISA mission is to have three spacecraft that each fire highly accurate lasers at each other to measure their positions exactly. The theory is that whenever a gravitational wave ripples by, it will cause the spacecraft to move slightly, altering their distance from each other. The Pathfinder will take into space two test 46-millimetre (1.8-inch) gold-platinum cubes that will be in perfect gravitational free fall and laser sensors will measure their position to high precision to test how well the laser-measuring system works.



The LISA Pathfinder science and engineering team in the clean room with the spacecraft in the testing chamber behind them



The science module of
LISA Pathfinder about to
undergo thermal tests at the
IABG facility in Ottobrunn,
Germany, in March 2015

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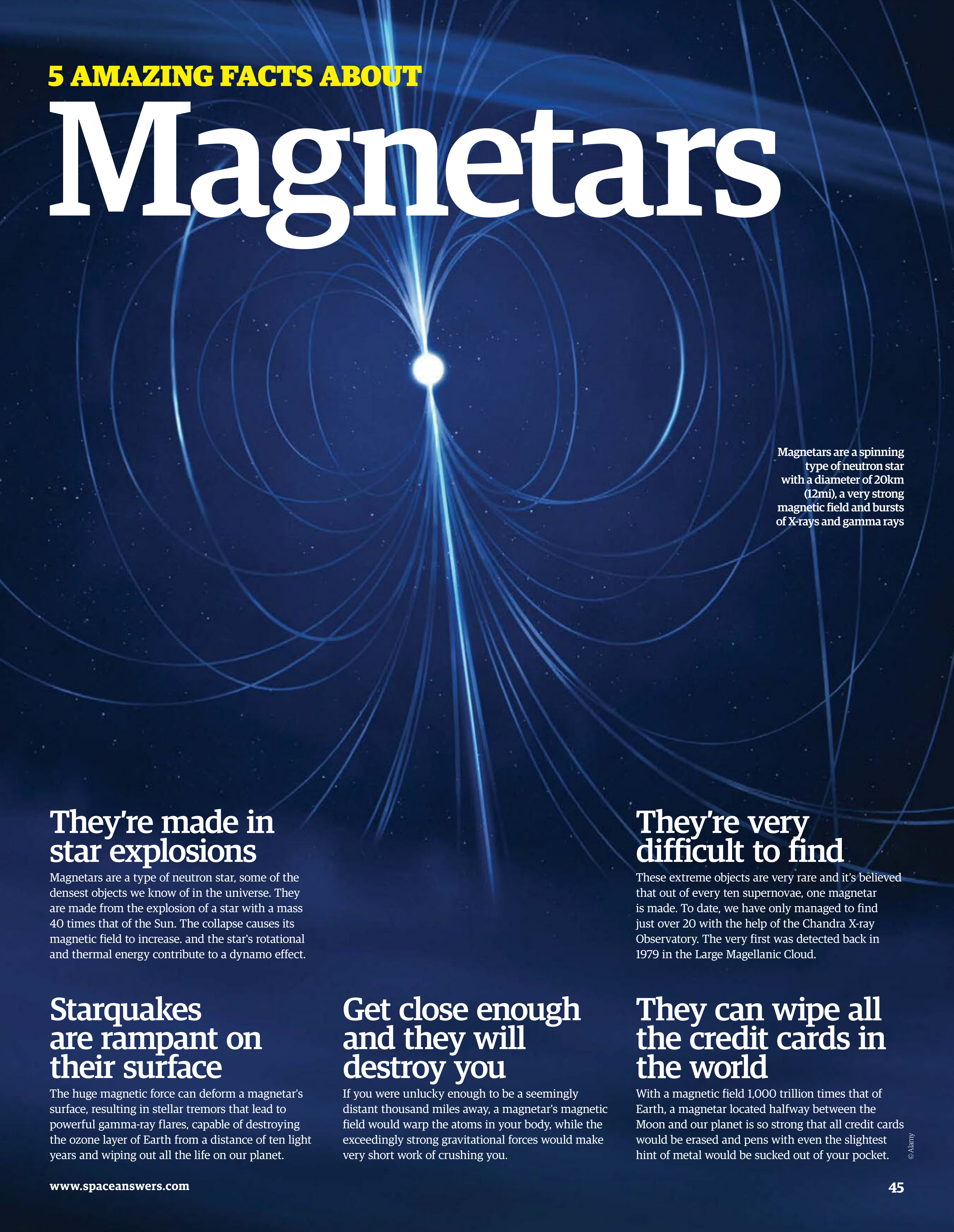
5 AMAZING FACTS ABOUT

Magnetars



Magnetars are a spinning type of neutron star with a diameter of 20km (12mi), a very strong magnetic field and bursts of X-rays and gamma rays

They're made in star explosions

Magnetars are a type of neutron star, some of the densest objects we know of in the universe. They are made from the explosion of a star with a mass 40 times that of the Sun. The collapse causes its magnetic field to increase. and the star's rotational and thermal energy contribute to a dynamo effect.

They're very difficult to find

These extreme objects are very rare and it's believed that out of every ten supernovae, one magnetar is made. To date, we have only managed to find just over 20 with the help of the Chandra X-ray Observatory. The very first was detected back in 1979 in the Large Magellanic Cloud.

Starquakes are rampant on their surface

The huge magnetic force can deform a magnetar's surface, resulting in stellar tremors that lead to powerful gamma-ray flares, capable of destroying the ozone layer of Earth from a distance of ten light years and wiping out all the life on our planet.

Get close enough and they will destroy you

If you were unlucky enough to be a seemingly distant thousand miles away, a magnetar's magnetic field would warp the atoms in your body, while the exceedingly strong gravitational forces would make very short work of crushing you.

They can wipe all the credit cards in the world

With a magnetic field 1,000 trillion times that of Earth, a magnetar located halfway between the Moon and our planet is so strong that all credit cards would be erased and pens with even the slightest hint of metal would be sucked out of your pocket.

© Alamy

Why is Mars so popular?

We're so fascinated by the Red Planet that people are willing to settle there permanently. Find out why we persist with missions to Mars

In 1960, the Soviet Union chose Mars as its target for the first interplanetary probes. Although they failed, these attempts were just the first of decades of Mars missions. The first successful flyby took place five years later with NASA's Mariner 4, which sent back the first pictures of the Martian surface. Since then, more ships have been sent to Mars than any other planet in our Solar System, and more than half of our total attempts to visit Mars have failed. Even some of the more recent missions haven't made it, yet we persist. Luckily we've learned a lot from the successful missions to Mars, and we're striving to learn more about this inhospitable, but intriguing planet.

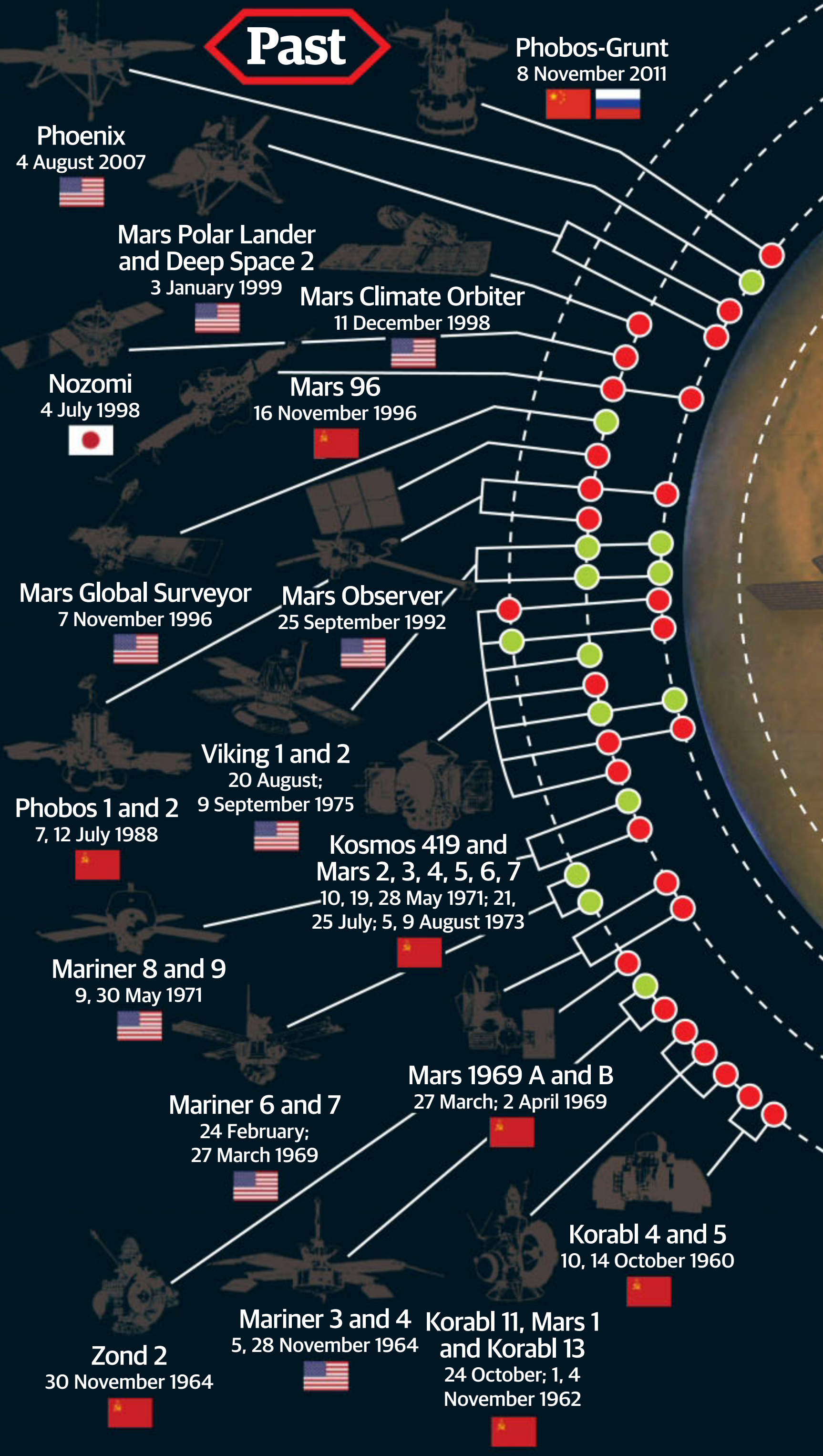
So far we know that Mars has an average temperature of -63 degrees Celsius (-81 degrees Fahrenheit). Its atmosphere contains mostly carbon dioxide and water vapour, and it has a gravity that's less than half that of the Earth's. Mars does have some things in common with our planet, though. For example, it is tilted on its axis, has a 24-hour day, and has seasons. It is also the closest terrestrial planet with a hospitable atmosphere. Our closer neighbour, Venus, has a constant temperature of around 460 degrees Celsius (860 degrees Fahrenheit) and a toxic, hazy atmosphere that makes it difficult to determine what's happening on the surface. Not exactly a friendly place to visit.

The biggest source of fascination with the Red Planet has been the search for water. We have long speculated that Mars was once a wet world due to the discovery of formations on the terrain that looked as though they were created by floodplains and flowing rivers. However, in an exciting new development on 28 September, NASA announced that its Mars Reconnaissance Orbiter had found evidence of periodic flows of liquid water on Mars' surface. Since water is integral to life on Earth, the presence of water on Mars could mean complex life once existed there too. We explore space in part to find out if any other life forms exist, so the possibility that it might have resided on Mars is enough to keep us going back. Mars' potential to sustain life is also why some people are willing to entertain the idea of creating colonies and settling there permanently.

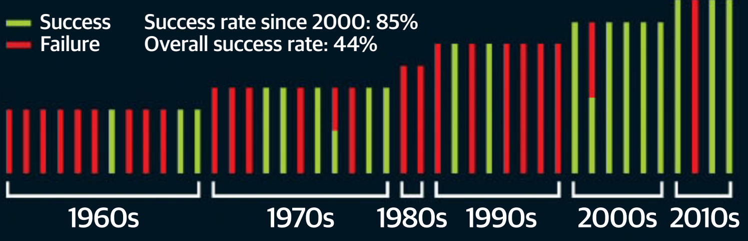
Missions by country

USA: 21 (15 successful)
Russia*: 19 (3 successful)
Japan: 1 (failure)
ESA: 1 (partly successful)
China†: 1 (failure)
India: 1 (successful)
UAE: (1 mission planned)

* includes both USSR (☭) and Russia
† joint mission with Russia



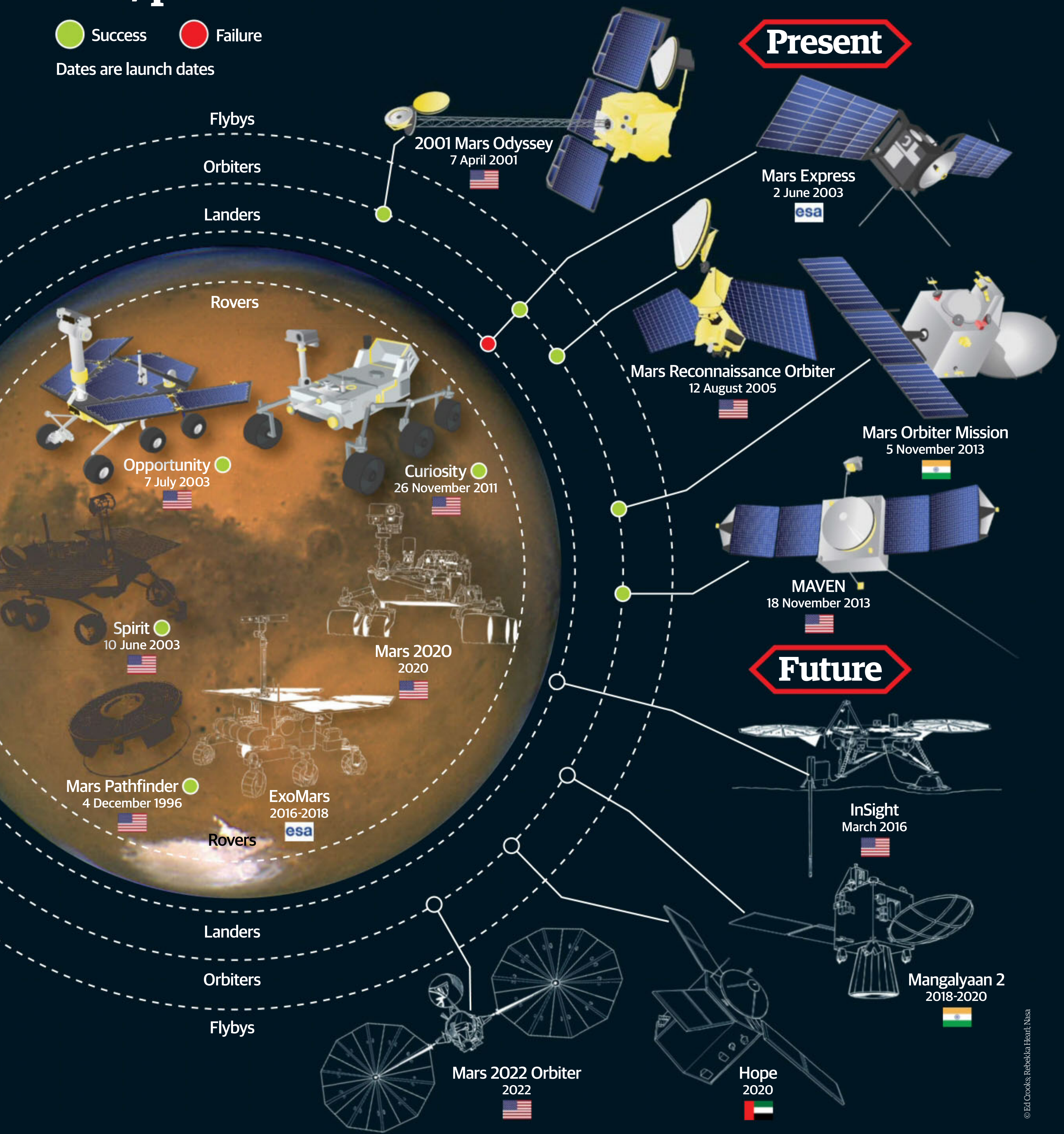
Successes and failures by decade



Past, present and future missions to the Red Planet

🟢 Success 🔴 Failure

Dates are launch dates



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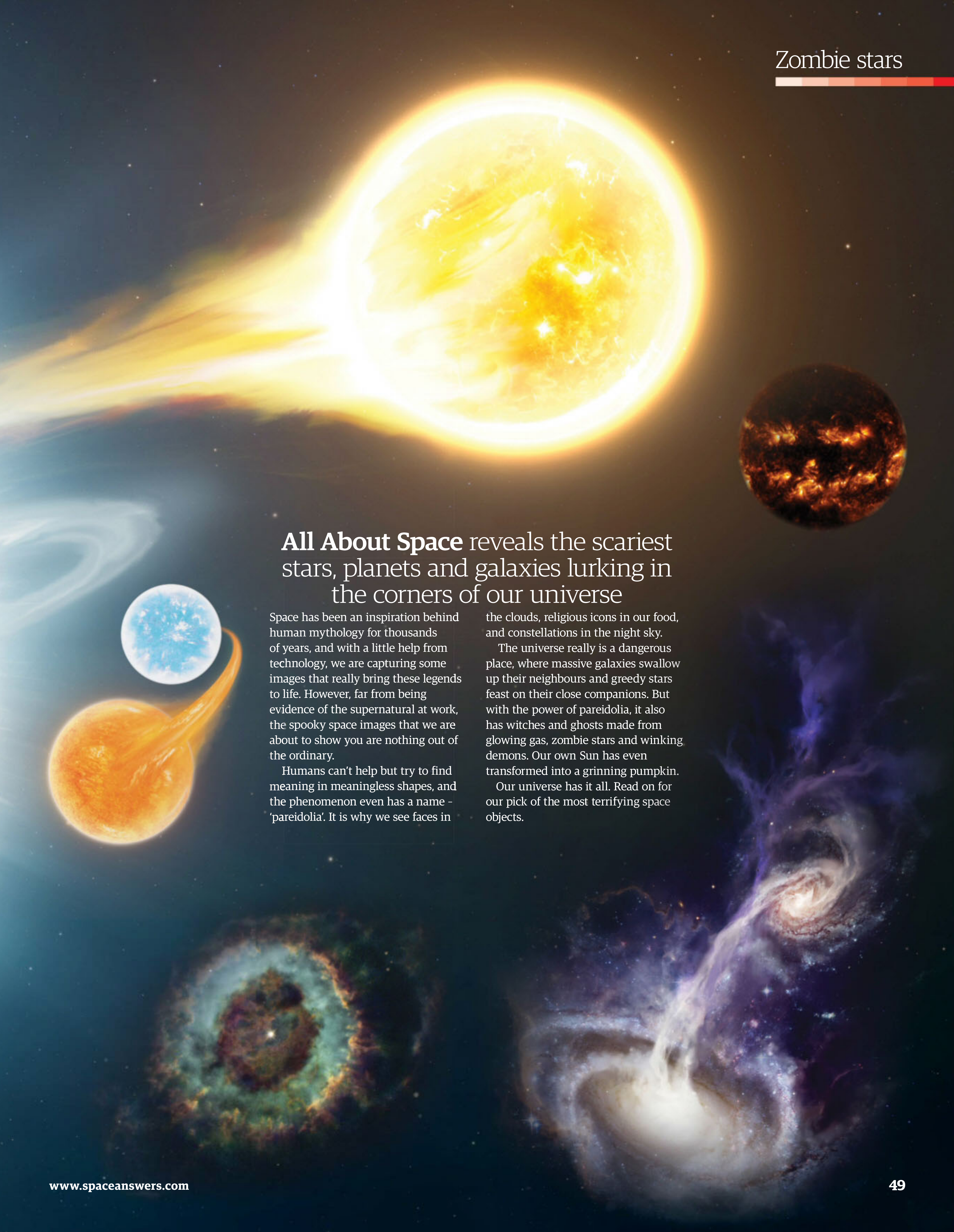
ZOMBIE STARS

+10 other terrifying space objects

Written by **Laura Mears**



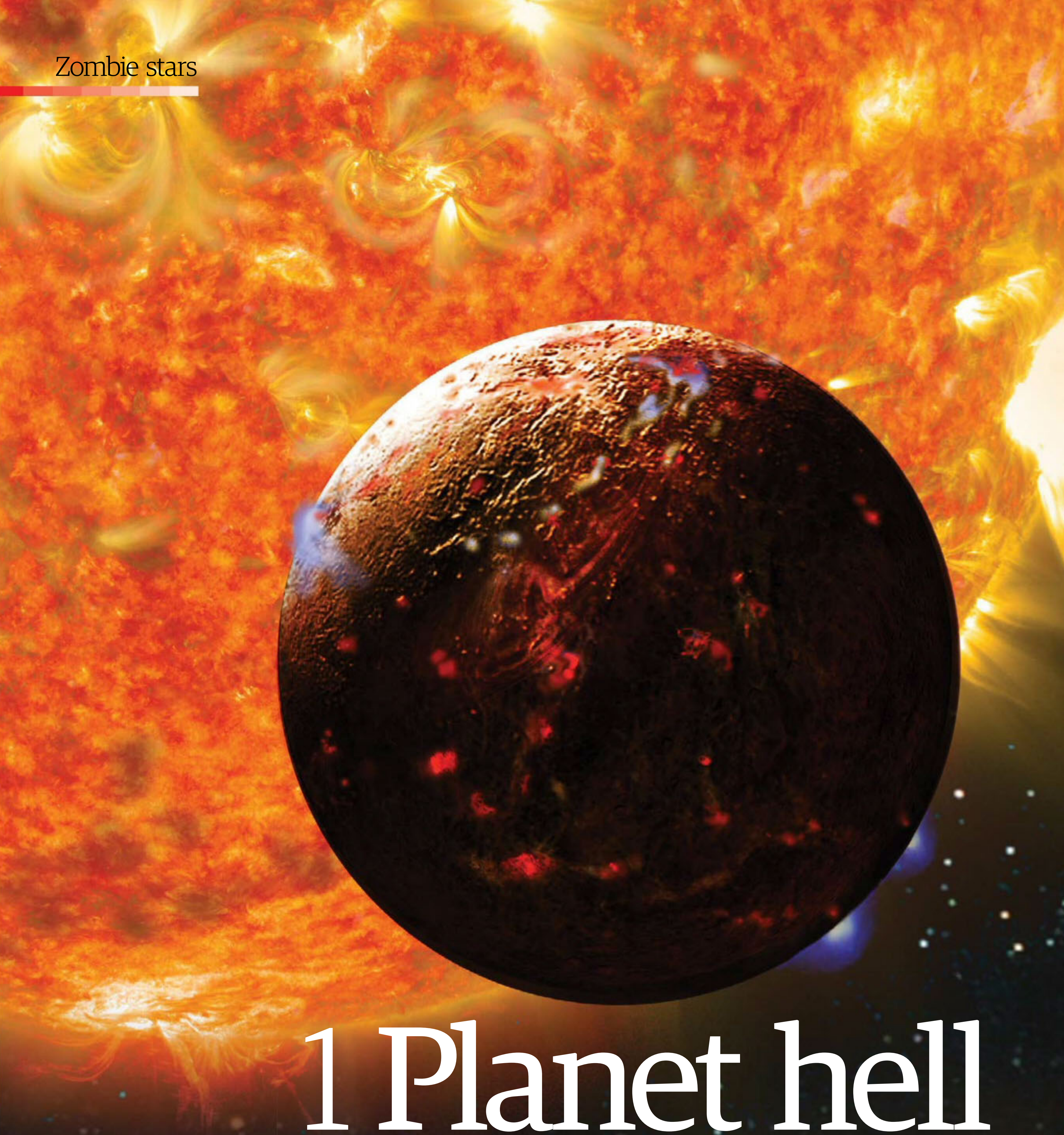
All About Space reveals the scariest stars, planets and galaxies lurking in the corners of our universe

Space has been an inspiration behind human mythology for thousands of years, and with a little help from technology, we are capturing some images that really bring these legends to life. However, far from being evidence of the supernatural at work, the spooky space images that we are about to show you are nothing out of the ordinary.

Humans can't help but try to find meaning in meaningless shapes, and the phenomenon even has a name – 'pareidolia'. It is why we see faces in the clouds, religious icons in our food, and constellations in the night sky.

The universe really is a dangerous place, where massive galaxies swallow up their neighbours and greedy stars feast on their close companions. But with the power of pareidolia, it also has witches and ghosts made from glowing gas, zombie stars and winking demons. Our own Sun has even transformed into a grinning pumpkin.

Our universe has it all. Read on for our pick of the most terrifying space objects.



1 Planet hell

CoRoT-7b is one of the most Earth-like planets ever discovered, but this alien world is no place for a human. Just over one and a half times the size of our own planet, and almost five times the mass, CoRoT-7b more closely resembles a depiction of hell than a second home. Its star, CoRoT-7 is younger than ours, and CoRoT-7b orbits at around 2.5 million kilometres (1.5 million miles) - 60 times closer than the Earth is to the Sun. This journey takes just over 20 hours, and the planet skims so close that its surface melts under the daylight and the rocks boil away into space.

Scientists think CoRoT-7b could once have been a gas giant with a mass similar to Saturn. It originally orbited around 50 per cent farther away from its star, but the searing heat stripped away the outer layers of gas. The planet is thought to have lost several Earth-masses of material, and it decreased in size, gravitational tides changed its orbit, bringing CoRoT-7b even closer to the heat of its star.

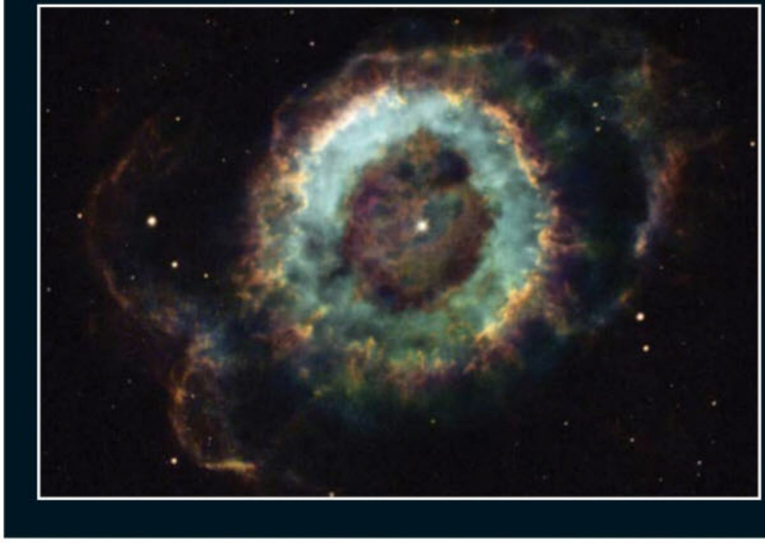
2 Little Ghost Nebula

The wispy halo of the Little Ghost Nebula surrounds a white dwarf star in the direction of the constellation of Ophiuchus. The white dwarf emits high-energy ultraviolet radiation, which slams into the clouds of dust and gas surrounding it, exciting the particles and causing them to glow. The main ring is made from a combination of ionised hydrogen, oxygen and nitrogen, and each emits different wavelengths of radiation.

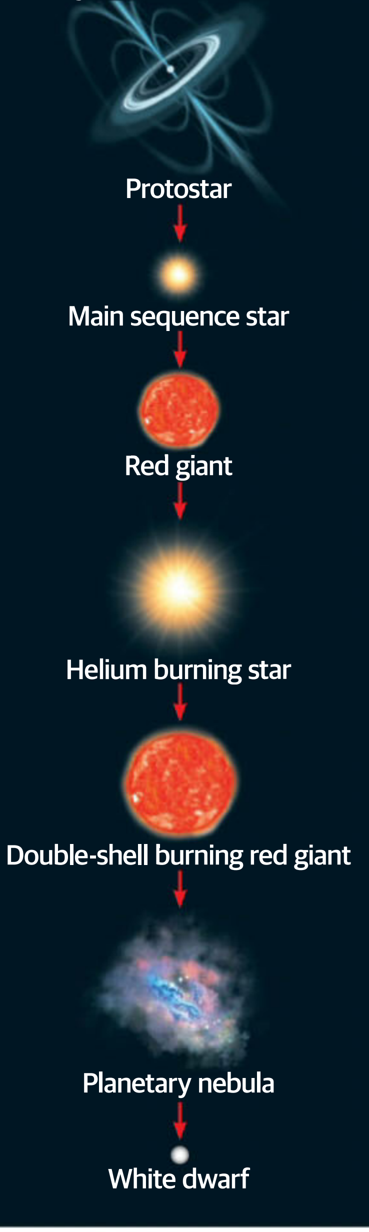
The Little Ghost is a planetary nebula, created as the star at its centre ran out of fuel. In fact, it's a ghostly premonition of the fate of our own Solar System.

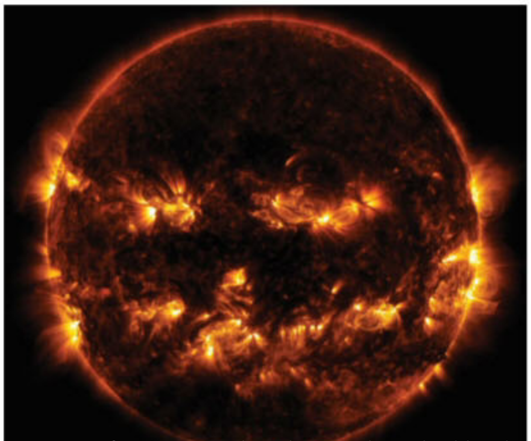
Once similar in size to our own Sun, the star at the heart of the Little Ghost Nebula ran out of hydrogen fuel, and as it switched to using helium, the temperature soared. The intense heat caused the star to swell, forming a red giant.

The red giant tore through its supply of helium quickly, generating carbon in the process. The heavy ash crunched down towards the core of the star, and as it tumbled inwards, some ignited, producing shocks that jettisoned the outer layers of the atmosphere into space. The dust and gas that spilled out formed the Little Ghost Nebula.



Life cycle of a white dwarf





Images of two UV wavelengths are coloured gold and yellow, producing an eerie pumpkin-like Sun

3 Jack-o'-lantern Sun

NASA's Solar Dynamics Observatory is using three high-tech instruments to study the Sun's activity - one tracking ultraviolet radiation, one measuring the magnetic field, and another capturing images of the atmosphere. In October 2014, it watched as our star put on a Halloween mask.

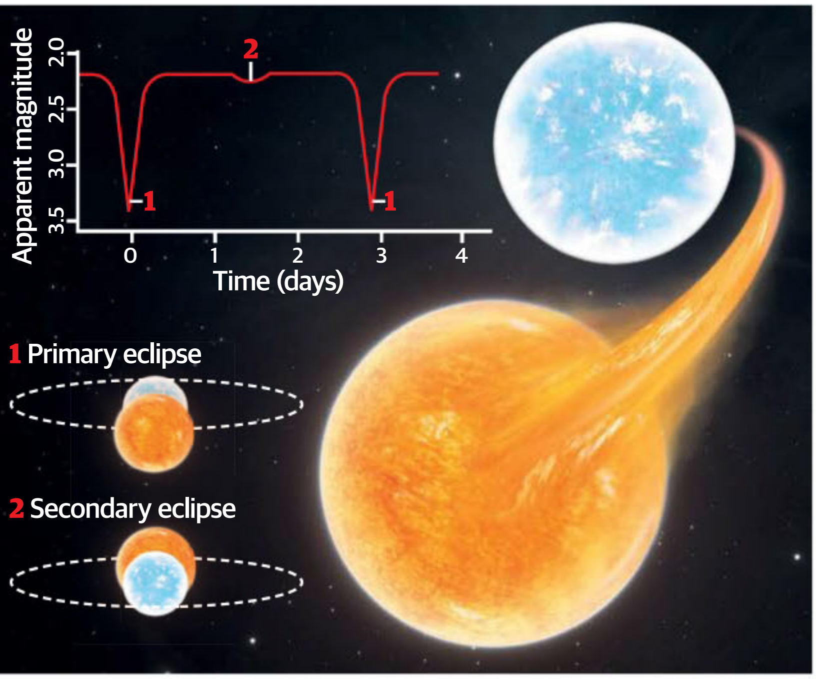
The temperature and pressure at the core of the Sun are so intense that atoms slam into one another and fuse, releasing huge amounts of energy. This powers the movement of streams of plasma - gas so hot that it has broken apart to form free charged particles. The movement of these charged particles transforms the Sun into a powerful magnet. The bright areas in this picture represent extreme ultraviolet light released in areas of intense magnetic pressure. The magnetic field lines inside the Sun are always moving, and sometimes areas of extreme magnetic pressure build up. This is similar to trying to force the north poles of two bar magnets together, but on a massive scale. Some of these regions of pressure burst through the surface of the Sun, taking streaks of plasma with them and forming visible sunspots.

5 Demon star

In Arabic, 'al Ghul' means 'the demon', and this sinister star lives up to its name in constellation mythology. It makes up the head of the Ancient Greek snake-haired monster Medusa in the constellation Perseus, and every few days its light dims dramatically, before returning to normal, as if Algol were winking at the Earth.

However, this gesture is far less sinister than it seems. It happens because Algol is actually a three-star system, and two of the stars are orbiting extremely close together. From Earth, we see their orbits edge-on, so at regular intervals, one star passes in front of the other, blocking our view. Most of the light we attribute to Algol is produced by a bright blue star, with a small proportion contributed by a dimmer red-yellow star. When the blue star passes in front of the yellow star, we barely notice the difference, but when the yellow star blocks our view of the blue star, the light changes dramatically.

Although Algol is not actually a winking demon, there is something sinister going on out there. The two stars are so close together that one is stealing gas from the other, like a stellar vampire sucking the life from its victim.



4 Zombie stars

According to NASA, supernovae are the largest explosions in space, and new evidence suggests that some might leave behind zombie stars. Type Ia supernovae happen in binary star systems where a white dwarf star is stealing hydrogen gas from its companion. As more and more matter accumulates, the white dwarf can become unstable, leading to a dramatic explosion that completely destroys the star.

Type II supernovae are more dramatic and are caused by the death of a massive star. As it runs out of fuel, the star crunches in on itself, releasing vast quantities of energy and leaving behind a dense neutron star, or even a black hole. Until recently, it was thought that exploding stars were always destroyed by the blast, but in 2012 scientists revealed a new type of survivable supernova. Like Type Ia supernovae, Type Iax supernovae are the result of white dwarf stars in binary systems, but this time they are stealing helium gas instead of hydrogen. The result is a much smaller explosion, allowing the damaged star to reappear once the dust has settled, like a zombie raised from the dead.

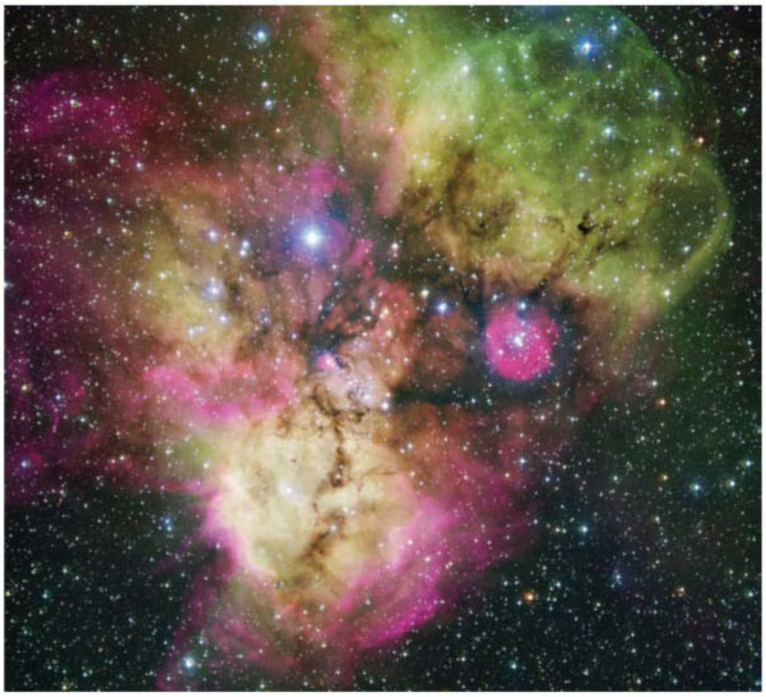
In 2014, NASA's Hubble Space Telescope captured a picture of one of these dim supernovae, and researchers are now waiting to see if a zombie star will be revealed. In 2015, the Hubble telescope will train its Advanced Camera for Surveys on the supernova remnant to see whether the star survived.

6 Franken nebula

In this bright stellar nursery, hot, blue stars are constantly emerging from the clouds of dust and gas, and their energetic emissions are sculpting a scary silhouette. NGC 2467 is a young open star cluster sometimes likened to Frankenstein's monster or a deathly skull, and in this image captured at the ESO, it is easy to see why.

NGC 2467 is just a few million years old, and is shrouded in large clouds of dust and gas. It is the birthplace of hundreds of new stars, and the energy that they release has been sculpting the nebula. The monster's lower eye is a star cluster known as Haffner 19, still encased in a cloud of partially ionised gas, and its right eye is a star called HD 64455. The nose is an elongated open cluster known as Haffner 18, containing around 50 massive young stars, and the lower jaw is being chiselled by a bright double or multiple star called HD 64315.

Over time, as these hot young stars continue to sculpt the clouds of the nebula, its eerie outline will change, but for now, it is truly a stellar monster.

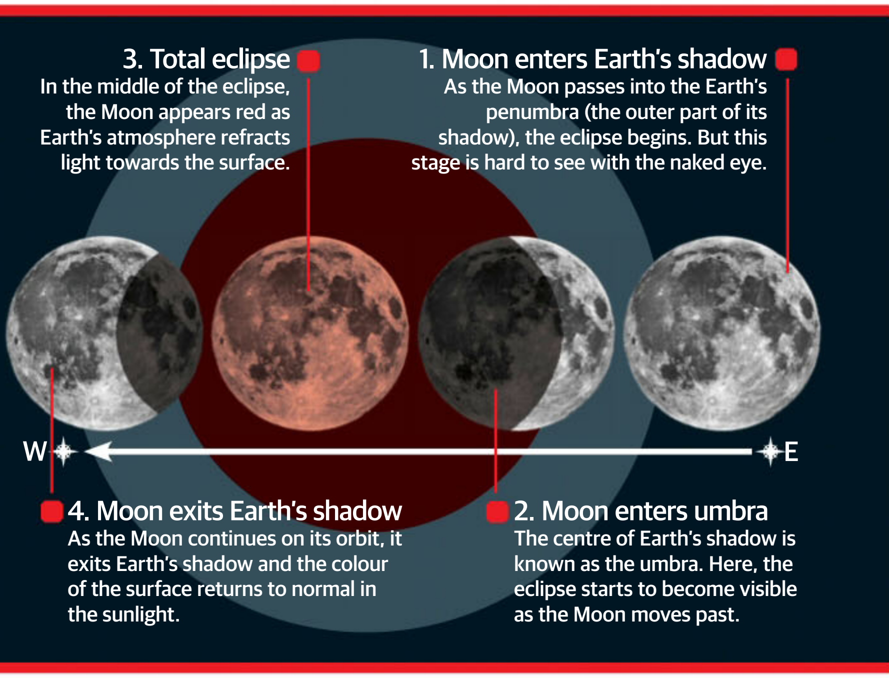


7 Blood Moon

During a total lunar eclipse, when the shadow of the Earth falls directly over the Moon, the surface can take on a reddish hue. To some people, this is the warning sign of an impending apocalypse.

When the Earth comes between the Sun and the Moon, some sunlight still strikes the surface, but along the way it has to pass through Earth's atmosphere. As it collides with the gas and dust particles, some of the light is scattered. Shorter wavelengths at the blue end of the spectrum scatter more, which is why the sky appears blue, and longer wavelengths at the red end of the spectrum scatter less. Some of this light is bent towards the Moon, hitting the surface and casting a blood-like glow – the exact shade varies depending on the conditions in the atmosphere at the time.

A blood-red Moon is referenced in the Bible, and over time mythology has built up around this strange phenomenon – a few people believe that four blood Moons in a row will signal the end of the world. On 28 September of this year, we witnessed the fourth in a series of blood Moons in the space of two years. Before the year 2100, we can expect to see six more of these events – but chances are, we're all going to be fine.



3. Total eclipse
In the middle of the eclipse, the Moon appears red as Earth's atmosphere refracts light towards the surface.

1. Moon enters Earth's shadow
As the Moon passes into the Earth's penumbra (the outer part of its shadow), the eclipse begins. But this stage is hard to see with the naked eye.

4. Moon exits Earth's shadow
As the Moon continues on its orbit, it exits Earth's shadow and the colour of the surface returns to normal in the sunlight.

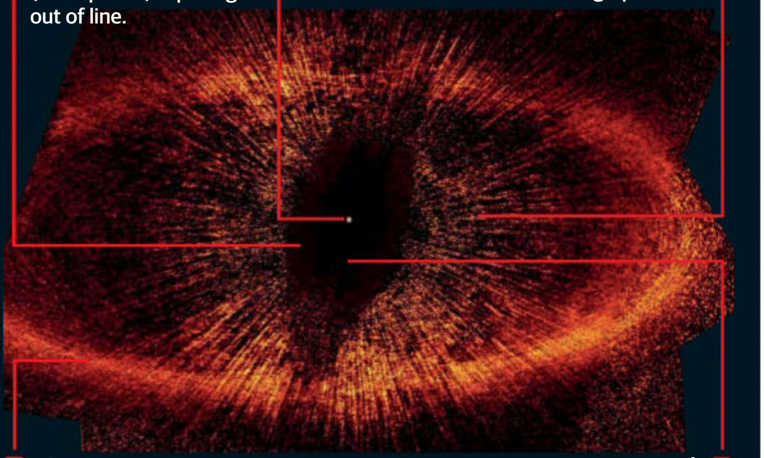
2. Moon enters umbra
The centre of Earth's shadow is known as the umbra. Here, the eclipse starts to become visible as the Moon moves past.

8 Space's evil eye

Fomalhaut is a white dwarf about twice the mass of the Sun, but take a look at this image from the Hubble Space Telescope and you might think that you're looking straight into the Eye of Sauron from *The Lord Of The Rings*.

Fomalhaut is surrounded by several discs of frozen dust, which are warmed by the star and emit a faint glow of infrared radiation. When the much brighter light of the white dwarf is blocked out (as in the image below), the faint light reveals the stunning detail of the eye-shaped debris.

The disc extends out to about five times the distance between Pluto and the Sun, and the patterns and distortion indicate that there are planets in the dust. By comparing photos taken at different times, researchers pinpointed the location of the first in 2008. After its discovery, many suggested it was probably a dust cloud. However, the latest evidence suggests that Fomalhaut b is a planet after all.



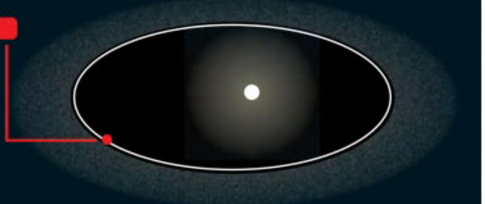
Ring centre
The centre of the ring is around 2.2bn km (1.4bn mi) from the star, indicating that something (like a planet) is pulling it out of line.

Star
The star at the centre of the system is bright and young and over two times the mass of the Sun.

Scattered light
The 'iris' of the evil eye is actually scattered light from the bright star that is hidden by the coronagraph mask.

Ring
The debris ring makes up the outline of the eye. Hubble has spotted a dust-covered planet orbiting just inside.

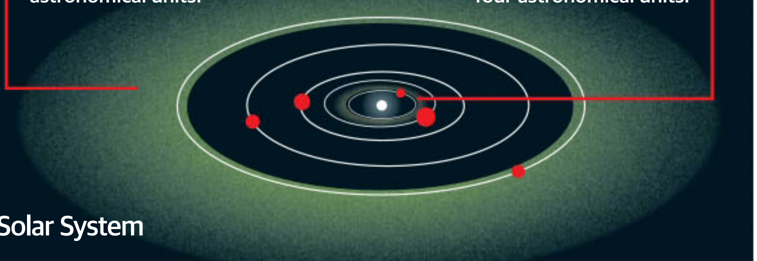
Star mask
The light from the star at the centre has been blocked out by a coronagraph in this image, allowing the structure of the rings to be examined in more detail.



Exoplanet Fomalhaut b
A planet has been spotted orbiting Fomalhaut just inside the ring of dust. This is similar to the position of Neptune on the inner edge of the Kuiper belt.

Kuiper belt
The Fomalhaut debris ring has a radius of more than 130 astronomical units. In comparison, the Kuiper belt is only around 50 astronomical units.

The asteroid belt
The asteroid belt is smaller still, beginning at around two astronomical units from the Sun, and ending at around four astronomical units.

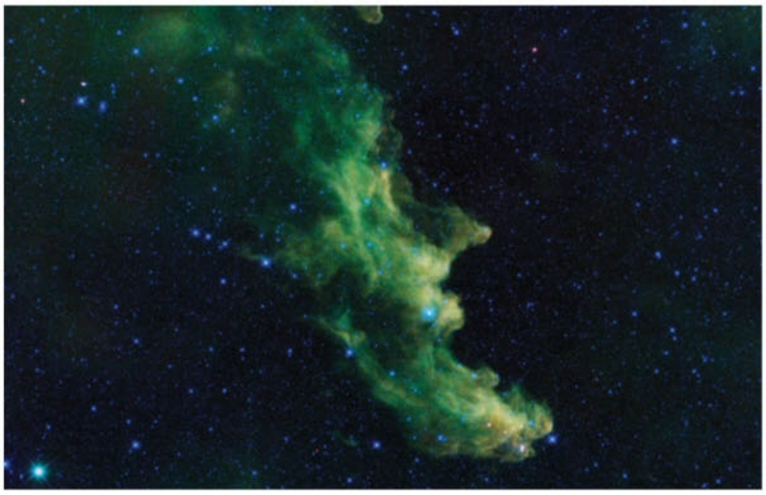


9 Stellar vampires

We'll meet cannibal galaxies shortly, but stars can be just as sinister. Many of the stars in our galaxy are part of 'binary systems', sharing their space with a stellar companion. The two orbit around a shared point known as their common centre of mass and, as they age, they often come a bit too close for comfort.

When a star starts to run out of hydrogen fuel, it swells to become a red giant. The gases around the edges can no longer be contained by gravity and they start to spill out into space. If two stars are close enough, the red giant's neighbour will start to suck up the excess. In many binary pairs, one star is feeding on its partner, using the gas to fuel its own internal fusion reactor. These vampire stars are effectively stealing the lifeblood of their neighbours.

In some cases, a red giant can get so big that it engulfs its companion star. Rather than feeding on the gas that spills away from the surface, this strange type of vampire orbits inside the expanded atmosphere, creating enormous friction, and causing even more of the gas to leak into space.



10 Witch Head Nebula

This wispy outline, with its hooked nose and curved chin, bears a striking resemblance to the profile of a traditional fairy tale villain. It is known as the Witch Head Nebula.

The Witch Head Nebula is a reflection nebula, so it does not produce any light of its own, but it is found to the west of the constellation of Orion, next to the blue supergiant star Rigel. Rigel is one of the brightest objects in the night sky, between 40,000 and 100,000 times more luminous than the Sun.

Even though it's over 40 light years from the nebula, the blue light that Rigel pours out into space illuminates the spooky silhouette of the Witch Head Nebula. It doesn't provide enough energy to ionise the gas and make it glow, but the light scatters as it passes through.

The dust that comprises the nebula is able to scatter blue light more easily than it is able to scatter red and, as a result, Rigel's blue shade is intensified. This is the same physical phenomenon that makes Earth's sky appear blue.

11 Cannibal galaxies

Massive galaxies grow by swallowing up the competition. Some examples are dramatic – like the famous Antennae Galaxies, which are in the process of merging right before our eyes – but even galaxies like our own have a cannibalistic past.

Andromeda is a spiral galaxy very similar to the Milky Way. Most of its stars are arranged into a flat disc, and the rest circle the galactic centre in a halo. Within this halo, scientists noticed a stream of debris, containing a group of metal-rich stars moving in the same direction.

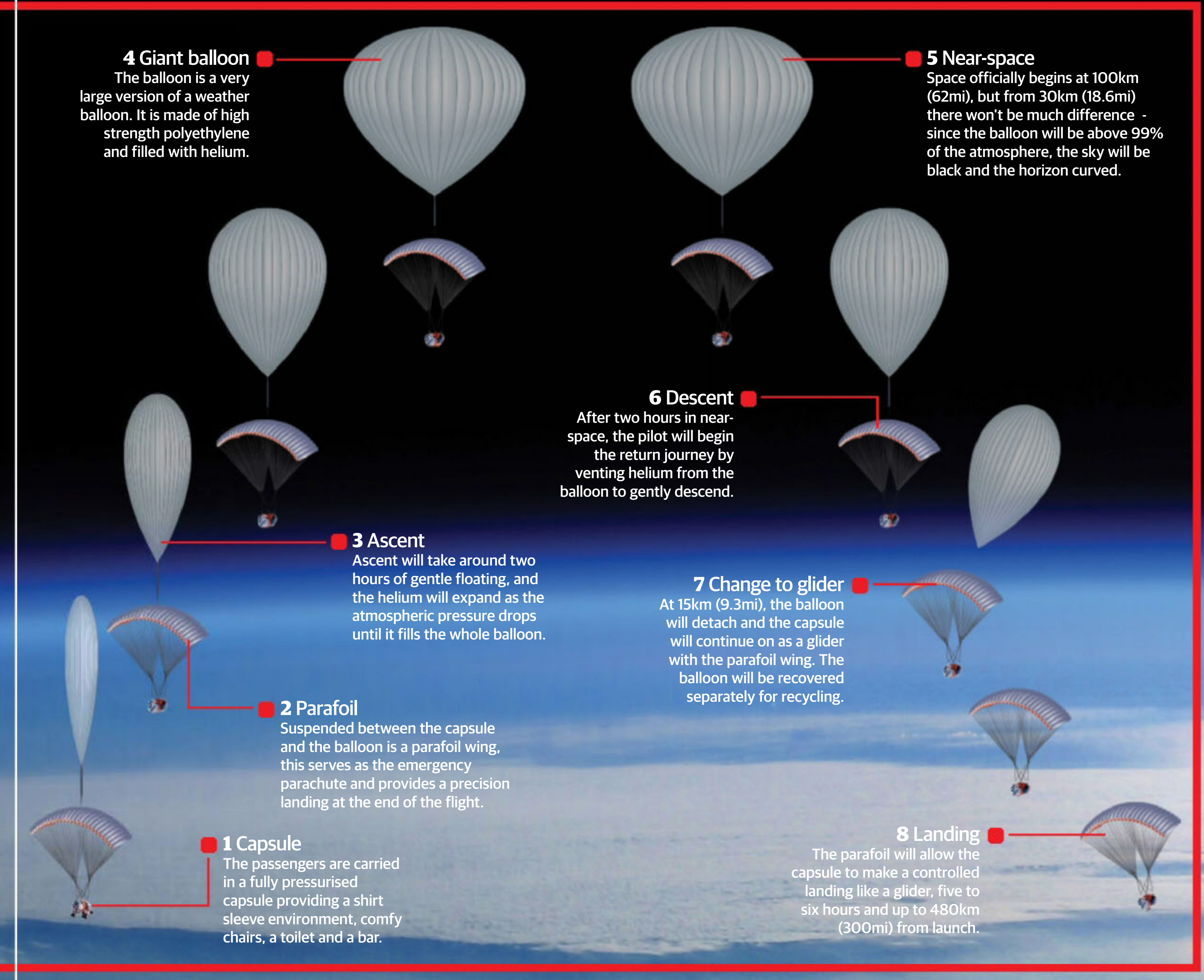
These stars started life in another galaxy; they orbit the galactic centre, but they still have some memory of the direction they were travelling in before their galaxy was swallowed up, so they continue to move as a group.

Andromeda is heading for another galactic feast, but this time it's on a collision course with the Milky Way, and we're due to merge in about 4.5 billion years. It is thought that there is a one in ten chance that the collision will fling the Sun out of the galaxy, but it is more likely that we'll end up close to the core of 'Milkomeda'.

© Tobias Roetsch; ESO; NASA

Giant space balloon tourism

Take a voyage to the edge of space with World View



1 Capsule
The passengers are carried in a fully pressurised capsule providing a shirt sleeve environment, comfy chairs, a toilet and a bar.

2 Parafoil
Suspended between the capsule and the balloon is a parafoil wing, this serves as the emergency parachute and provides a precision landing at the end of the flight.

3 Ascent
Ascent will take around two hours of gentle floating, and the helium will expand as the atmospheric pressure drops until it fills the whole balloon.

4 Giant balloon
The balloon is a very large version of a weather balloon. It is made of high strength polyethylene and filled with helium.

5 Near-space
Space officially begins at 100km (62mi), but from 30km (18.6mi) there won't be much difference - since the balloon will be above 99% of the atmosphere, the sky will be black and the horizon curved.

6 Descent
After two hours in near-space, the pilot will begin the return journey by venting helium from the balloon to gently descend.

7 Change to glider
At 15km (9.3mi), the balloon will detach and the capsule will continue on as a glider with the parafoil wing. The balloon will be recovered separately for recycling.

8 Landing
The parafoil will allow the capsule to make a controlled landing like a glider, five to six hours and up to 480km (300mi) from launch.

Giant space balloon tourism

"The capsule will be equipped with a bar and internet access"

If you are considering becoming a space tourist and are feeling a little nervous after Virgin Galactic's developmental problems, then Arizona-based World View Enterprises might be the answer. World View is developing a balloon-based system to offer trips to near space, hopefully starting in 2016.

The rocket-based projects currently in the works will boost you up to a few Gs, either from the ground or dropped off a carrier aircraft depending on the company. They will fly a ballistic path called a parabola that sticks wildly out into space. This will give you a few minutes at the top to experience zero gravity and admire the view before you have to strap in again as you plunge back into the atmosphere. Virgin's price is £165,000 ($250,000), which includes training, but you will only actually be in space for a few minutes of the flight – World View's plan is much gentler and, somewhat, better value.

The company's craft consists of a specially designed capsule suspended from a stadium-sized helium balloon, made of polyethylene – a material that's primarily used for plastic bags. Before you make your voyage into space, the balloon will look a little small, with a long stretch of uninflated plastic. This is because the helium expands significantly as the altitude increases and the balloon must allow space for this change. The capsule is a pressurised cylinder, so that the passengers won't need to wear special suits or oxygen systems.

Rather than the noise, vibration and acceleration of a rocket trip, take off will be a stately affair, with the balloon gradually ascending to 30 kilometres (18.6 miles) altitude over two hours. The capsule will be equipped with a bar, a toilet and internet access. It is worth pointing out that this balloon won't take you fully into space but to a height that's near-space – space starts at 100 kilometres (62 miles) - but you will be above 99 per cent of the atmosphere, the sky will be black, and you will be able to see the curve of the Earth. And all for a bargain price of £50,000 ($75,000), which translates to £135 ($200) per minute.

The balloon stops ascending when the helium has expanded to fill all the plastic, so to begin descent the pilot will start to vent gas, causing it to become heavy. Incorporated between the capsule and the balloon from launch is a parafoil wing, like a rectangular parachute but stiffened with spars so it doesn't need to fall to fill up. This serves as the emergency back-up during the balloon flight but also takes over to allow a precision landing on the way back. Once the balloon has dropped to 15 kilometres (9.3 miles) the capsule and parafoil separate from the balloon and continue descending as a glider, this provides much more control over the landing than simply floating down towards the ground. The gliding capsule will eventually make a gentle touchdown on retractable skids around five to six hours and up to 480 kilometres (300 miles) from launch before a private aircraft takes you home. The balloon will be recovered separately for recycling.

Outlandish as it may sound, World View is making steady progress towards its goal and recently demonstrated the world's highest parafoil flight – the key technology in bringing back its passengers in safety and comfort. World View now hopes to make its first complete flights towards the end of 2016.

Passengers will have plenty of time to take in the incredible views of Earth, as the capsule remains at its maximum altitude for around two hours

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The new search for ALIEN LIFE

The next ten years could make or break the hunt for another intelligent civilisation

Written by Jonathan O'Callaghan

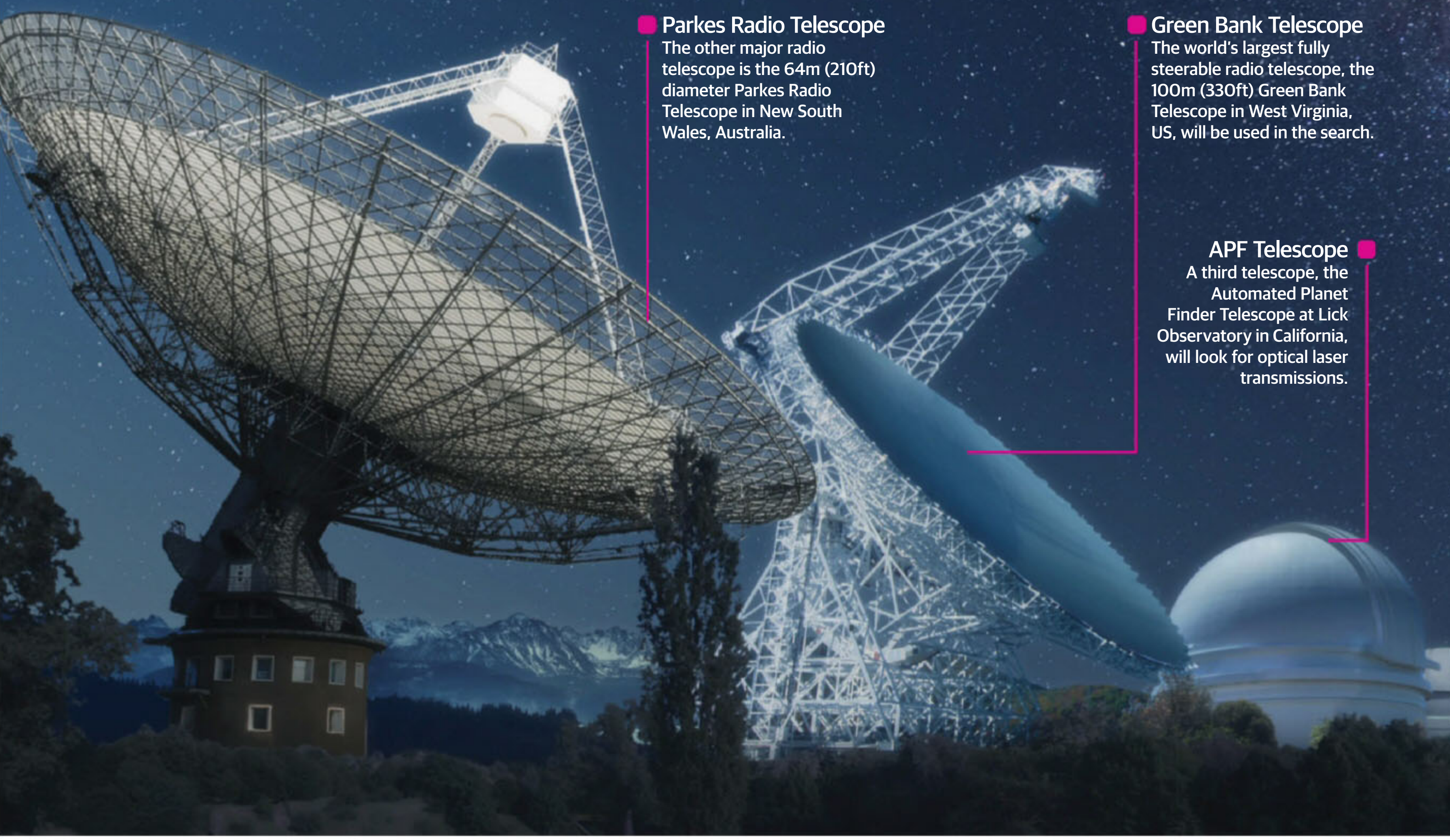
The search for extraterrestrial intelligence, or SETI, has always been a fringe science. Since it began in the mid-20th century, scientists involved in the field have had to fight for scraps of funding, often to ridicule from the public and media alike for what many consider a fruitless task. But now, thanks to a Russian billionaire, SETI is no longer going to be an also-ran - it is about to join the upper echelons of astronomy and, if a positive detection is made, those scientists once on the fringe could find themselves propelled into a whole new limelight.

In July, it was revealed that investor Yuri Milner, who has Facebook, Twitter and Alibaba on his portfolio, would be funding a $100 million (£65 million) project known as Breakthrough Listen. It will be the most extensive search for life outside the Solar System to date. Using the finest telescopes around the world, this ten-year project will be unprecedented in its scope and scale.

Considering the numbers, the chances that we are not alone in the universe are looking increasingly slim. Hundreds of billions of Earth-like planets likely reside in our galaxy, itself just one of hundreds of billions of galaxies. Is it possible that only one planet, Earth, sustained life? That is the answer we want, perhaps need, to know.

Breakthrough Listen

How this groundbreaking project will search for intelligent life beyond the Solar System



Parkes Radio Telescope
The other major radio telescope is the 64m (210ft) diameter Parkes Radio Telescope in New South Wales, Australia.

Green Bank Telescope
The world's largest fully steerable radio telescope, the 100m (330ft) Green Bank Telescope in West Virginia, US, will be used in the search.

APF Telescope
A third telescope, the Automated Planet Finder Telescope at Lick Observatory in California, will look for optical laser transmissions.

That does not mean this search will be successful. Astronomer Sara Seager, a professor at the Massachusetts Institute of Technology (MIT), tells All About Space that she rates the chances of the project finding alien life as "low". But despite the odds, she believes that the search for extraterrestrial life is a "no-brainer", adding: "Why wouldn't we do it? Imagine if the aliens were everywhere but we were too conservative to even try to listen."

And that is precisely why this search for life is so important. In fact, that exact sentiment can be seen in one of the first papers to propose the search for extraterrestrial intelligence, titled Searching for Interstellar Communications. Penned by astrophysicists Giuseppe Cocconi and Philip Morrison in September 1959, it stated: "The probability of success is difficult to estimate; but if we never search, the chance of success is zero."

Since then, the search for life has been stop-start, and not without its share of problems and false dawns. The year 1960 saw American astronomer Frank Drake use the newly built Tatel Radio Telescope at Green Bank in West Virginia to carry out the first direct search, known as Project Ozma. This search looked around frequencies at the hydrogen end of the spectrum, which Drake thought transmissions would edge towards due to the Doppler shift. Of course, it was unsuccessful. The following year, Drake would devise his famous Drake Equation to predict the probability of life elsewhere - more on that later.

In the rest of the Sixties, the Soviet Union dominated SETI, observing large chunks of the night sky at once. But by the Seventies their interest had waned, leaving a team of experts in the US to take up the reins. They produced a study known as Project Cyclops for NASA's Ames Research Center in Mountain View, California, detailing how to search for intelligent signals. It remains a guideline for much of SETI today.

After years of study and planning, NASA finally

> "Breakthrough Listen will be the most sensitive, comprehensive and intensive search for intelligent life ever undertaken" **Andrew Siemion, University of California, Berkeley**

Beyond
Signals will also be looked for broadly in the 100 nearest galaxies, 100,000 to 11 million light years away.

Milky Way
The centre of our galaxy and the entire galactic plane as seen from Earth will also be studied for radio signals.

Searching nearby
The two radio telescopes, and maybe others at a later date, will study the closest 1 million stars to Earth for radio signals from an intelligent race.

The proponents of Breakthrough Listen. From left to right: Yuri Milner, Stephen Hawking, Martin Rees, Frank Drake, Ann Druyan and Geoff Marcy

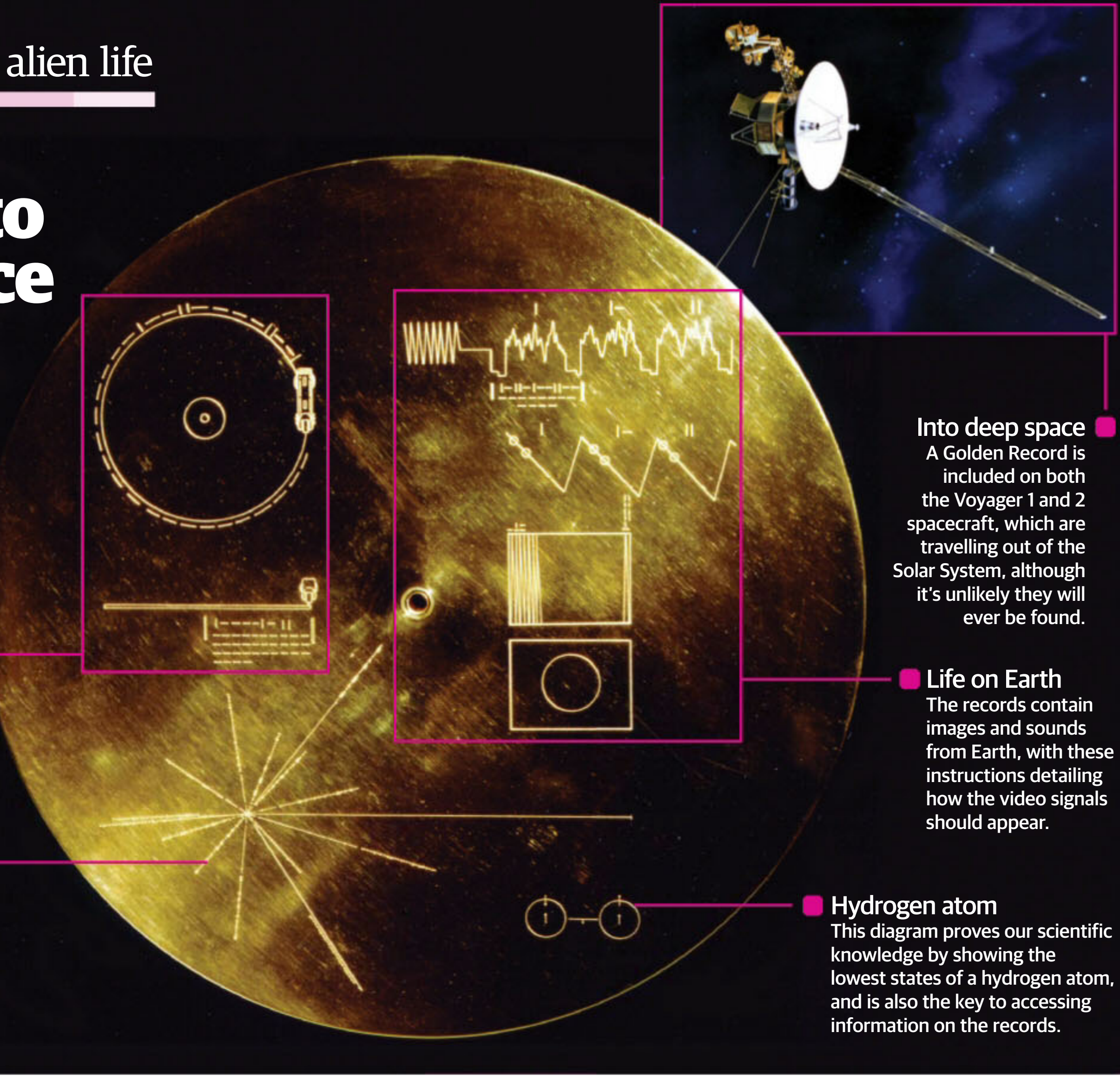
had a definitive strategy in place to begin SETI in earnest by 1992. Sadly, Congress terminated funding the following year. But SETI lived on, in the form of the not-for-profit SETI Institute in California, and other attempts began to spring up around the world. In 2007, the Allen Telescope Array was built at the Hat Creek Radio Observatory in California, where much of the modern SETI is done. Funding shortfalls remain a problem, though.

What have they been looking for? Signals. Since World War Two we have been firing out encoded electromagnetic radiation in all directions, and if anyone is within 75 light years or so and looking in the direction of Earth with similar technology, they will know there is intelligent life here. So, it makes sense that if there is other intelligent life out there, perhaps more advanced, they likely went through similar stages of technology as us, and must certainly have communicated in a similar manner at some point or other. There may be different forms of communication we are yet to discover but, for now, this is all we know. So, it makes sense to look for other signals that we know exist. "We are assuming that other intelligent civilisations think like we do and would use similar technology for long-distance space communication," says Seager. "The best-case scenario is that intelligent life forms are actually using radio signals and are sending a message directly to Earth."

If we do find a signal, what then? Do we send

Message to outer space

The Voyager Golden Records are an example of how to communicate using maths and astronomy



Into deep space
A Golden Record is included on both the Voyager 1 and 2 spacecraft, which are travelling out of the Solar System, although it's unlikely they will ever be found.

How to play
Shown are instructions on how to play the Golden Record with a stylus, included on each spacecraft.

Life on Earth
The records contain images and sounds from Earth, with these instructions detailing how the video signals should appear.

We are here
This diagram shows the location of the Sun relative to 14 pulsars – rapidly rotating neutron stars that act as beacons.

Hydrogen atom
This diagram proves our scientific knowledge by showing the lowest states of a hydrogen atom, and is also the key to accessing information on the records.

How to talk to aliens

Breakthrough Message
In tandem with Breakthrough Listen, this competition will encourage discussion on possible messages to send to another civilisation.

Not guaranteed
There is no definitive plan to send messages; this is merely a discussion.

Prize money
There is a pool of prizes for the best messages totalling $1 million (£650,000).

How to communicate
Entrants must devise ways to communicate in a universal language, such as mathematics.

All about content
The digital messages are asked to be representative of humanity and planet Earth.

Enter the competition at:
breakthroughinitiatives.org

a message back? Such an action would not be unprecedented. Besides the Voyager spacecraft carrying Golden Records that describe Earth in detail, we have been constantly broadcasting information for approaching a century. In 1974, meanwhile, a specific message was sent out containing information about Earth hidden in code, called the Arecibo message, towards the Great Cluster in Hercules, M13, about 25,000 light years away from Earth. The Breakthrough Initiatives will hold a competition called Breakthrough Message to ask members of the public what sort of message they think we should send to any potential intelligent civilisation.

There's just one problem: where is everyone? If habitable planets are so abundant, then surely we should have heard something by now? This is known as the Fermi Paradox, with various solutions suggested. Perhaps space is too vast for meaningful communication. Perhaps civilisations blow themselves up before they have a chance to communicate. Or perhaps we really are alone in this vast universe. Our best bet at the moment to find out is to methodically search each and every star for signs of artificial signals within our range of detection. The process is painstakingly slow, though – just a fraction of the total stars in the Milky Way have been studied so far.

That's where the Breakthrough Listen project comes in. While SETI has been restricted to a few telescope arrays around the world so far, Milner is pouring money into the project so that it can afford to buy serious time on some of the most powerful telescopes in the world. "With Breakthrough Listen, we're committed to bringing the Silicon Valley approach to the search for intelligent life in the universe," says Milner. "Our approach to data will be open and taking advantage of the problem-solving power of social networks." Of the $100 million (£65 million), one third will obtain thousands of hours of time on radio telescopes, another will fund research and development of new technologies, and the final third will be used to hire astronomers. $2 million (£1.3 million) will be used to secure 20 per cent of the annual observing time in 2016 of the world's largest fully steerable radio telescope, the Robert C Byrd Green Bank Telescope (GBT) in West Virginia, United

> "With Breakthrough Listen, we're committed to bringing the Silicon Valley approach to the search for intelligent life in the universe" **Yuri Milner**

States. Additional funds will secure 25 per cent of the annual observing time of the Parkes Radio Telescope in Australia from October 2016 for five years.

Observing time on other telescopes may be bought as well, and these telescopes will be used to systematically study stars and known exoplanets for signals. If there is anything emitting Earth-like signals around one of the million stars that will be studied, we'll know. "Breakthrough Listen will be the most sensitive, comprehensive and intensive search for intelligent life ever undertaken," says Andrew Siemion, director of the SETI Research Center at the University of California, Berkeley and one of the project leaders on Breakthrough Listen. "We will search more of the radio spectrum, at higher sensitivity, than any previous experiment." Siemion adds that Milner's enthusiasm for SETI was "fabulously unexpected".

Such is the power and size of the telescopes being used that this project is estimated to be 50 times more sensitive than any previous SETI programme. It will cover more than ten times the sky of anything before it and five times the amount of radio spectrum - all at 100 times the speed. A civilisation around one of the nearest 1,000 stars sending us a signal with the power of a common aircraft radar will be detectable. And in tandem with the radio search, the Automated Planet Finder Telescope at the Lick Observatory in California will be used by the project to search for optical laser transmissions. This could supposedly detect the energy output of a normal household light bulb from a distance of four light years. But the project isn't just limited to our own galaxy - while 1 million of the closest stars to Earth will be studied, in addition to the centre of our galaxy and entire galactic plane, Breakthrough Listen will also search for messages from the 100 closest galaxies to the Milky Way.

> "Right now there could be messages from the stars flying right through the room, through us all. That still sends a shiver down my spine" **Frank Drake**

It's fair to say the project has garnered significant interest. Among its advisors and proponents are Stephen Hawking, Astronomer Royal Lord Martin Rees, Seth Shostak of the SETI Institute, astronomer Frank Drake and Ann Druyan, who was married to the late Carl Sagan. And all of the data that the project will gather will be open to the public, giving anyone the opportunity to sift through to search for a signal. Existing endeavours like SETI@home will also be incorporated. "Right now there could be messages from the stars flying right through the room, through us all. That still sends a shiver down my spine," says Drake. "The search for intelligent life is a great adventure. And Breakthrough Listen is giving it a huge lift."

But let's be blunt: the chances of this succeeding are low, for a variety of reasons. The most obvious is that intelligent life more advanced than us might communicate in a manner we don't understand. It might be that no nearby life has developed technology like humans. And, perhaps most unnervingly, it may be simply that we are alone.

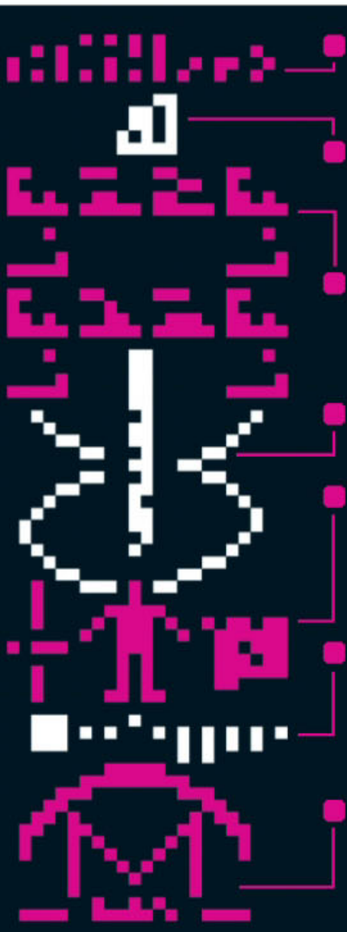
Life could be incredibly rare, and perhaps it was only Earth that somehow had exactly the right conditions for it to form. As the late author Sir Arthur C Clarke once said: "Two possibilities exist: either we are alone in the universe or we are not. Both are equally terrifying." The implications of us being alone would be profound, although it's an uncomfortable possibility no one wants to discover. But perhaps it would highlight just how important, and rare, Earth really is. "As always, absence of evidence is not evidence of absence," Siemion notes. "However, if after ten years of sustained searching we haven't found anything, we will surely have to take a moment to ponder the rarity of technologies like our own - and the care that we must take to ensure the long-term future of our rare example of a technologically capable species."

Of course, in the search for life, Breakthrough Listen is not the only project you should be excited about. In our own Solar System, new missions are in the process of being drawn up to find if some more

Decoding a message for alien life

Devised in 1974 by the likes of Frank Drake and Carl Sagan, the Arecibo message was broadcast into space in the direction of globular cluster M13 some 25,000 light years away

The Arecibo Observatory in Puerto Rico



Numbers
The numbers one to ten written in binary.

DNA
The atomic numbers of the elements that make up DNA.

Formula
The formulas for the sugars and bases in DNA.

Double helix
The structure of DNA.

Earth's population
The height of an average man and the human population on our planet.

Solar System
Our solar neighbourhood along with which planet the message is coming from.

Arecibo telescope
The dimension of the radio dish from which the message is being transmitted.

reachable locations were once habitable, or perhaps still are. For example, on Mars, we are now fairly certain the planet was wet and habitable a billion or so years ago. The next step, via an upcoming NASA rover in 2020 and further missions beyond, will be to look for actual signs of life now or in the past.

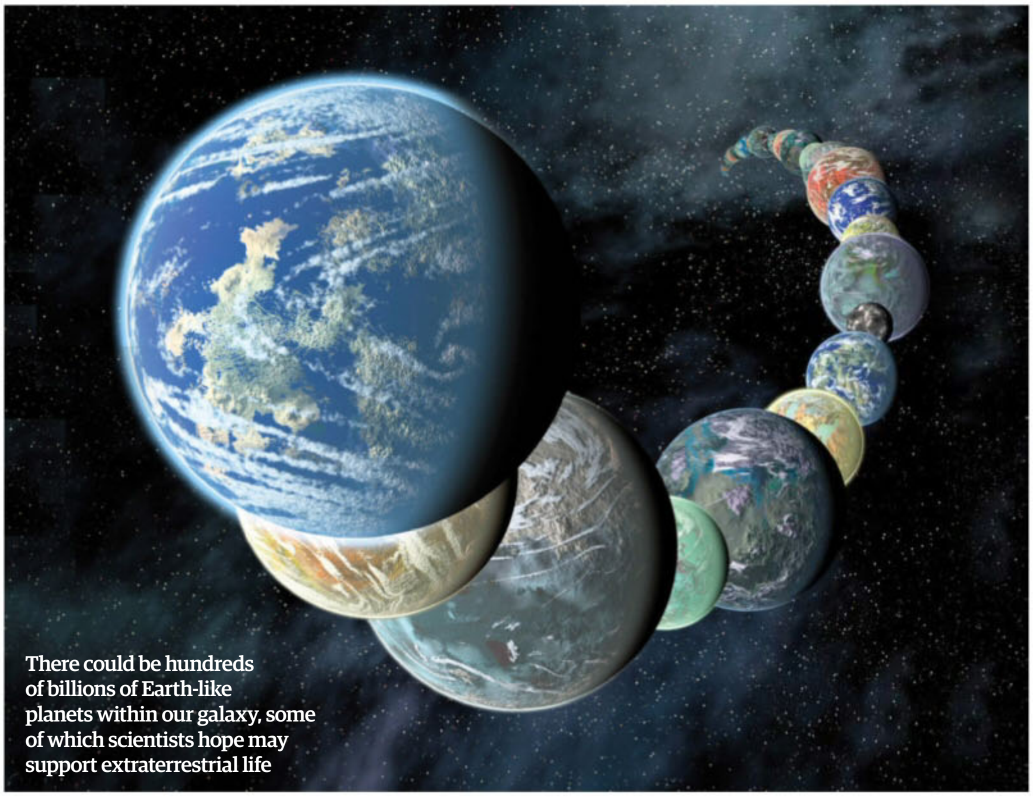
Elsewhere, some other destinations are becoming rather desirable; NASA is already in the process of researching a mission to send to study Jupiter's icy moon Europa by 2024 at the earliest. Europa is believed to have a vast underground ocean, containing more water than there is on Earth, and some say it could harbour small microbial life. Other moons in the Jovian system such as Ganymede also show promise for life forms, and are to be investigated by ESA's Jupiter Icy Moons Explorer (JUICE) from 2030 onwards. And that's not all; Saturn's moons Enceladus and Titan could also host microbial life in some form or another, and new missions to these have been touted.

Ultimately, though, anything found inside the Solar System will be microbial in size. It is in the rest of the galaxy where the real 'action' could be happening, and aside from the Breakthrough Listen project there are other things to look forward to. For one thing, astronomers are continuing to look for rocky planets in habitable zones of stars, with upcoming telescopes like NASA's Transiting Exoplanet Survey Satellite (TESS), due for launch in 2017, increasing our capabilities. The most powerful telescopes in existence will study the atmospheres of some of these worlds and will include NASA's upcoming James Webb Space Telescope (JWST), due for launch in 2018.

One thing is for sure, though. SETI is finding itself closer and closer to the spotlight, and if a discovery is made in the next ten years, those days of money problems will be long gone. Milner has gone on record to say he will continue funding the Breakthrough Initiatives beyond ten years, even if a detection is not made. But there's no doubt it would be a major disappointment if nothing is found.

To paraphrase Carl Sagan, if we are alone, it's an awful waste of space. ■

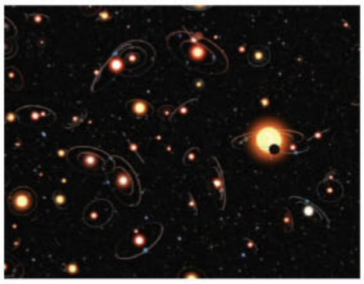
> "The best-case scenario is that intelligent life forms are actually using radio signals and are sending a message directly to Earth"
>
> **Sara Seager, MIT**



There could be hundreds of billions of Earth-like planets within our galaxy, some of which scientists hope may support extraterrestrial life

Chances of making contact

The Drake Equation is often used to estimate how likely it is someone else is out there



N =

This is the total number of civilisations in the Milky Way whose signals are detectable, according to the equation.

R^* ×

This is the rate of formation of stars that could host habitable planets.

f_p ×

The fraction of those stars that have planetary systems.

n_e ×

The number of planets per Solar System that could have a habitable environment.

What happens if we make contact?

Seth Shostak, director at the SETI Institute, explains what would happen if a signal were to be found

What's the procedure if we find alien life?
In the case of SETI, there is a set of protocols. I was the chair of an international committee that revised these protocols over the last five to ten years, and basically you have ample time to check out the signal, tell everybody, and don't respond without international agreement. That's basically all there is to it.

But the truth is, it doesn't really work that way. And we know that because, in the case of false alarms, you see what really happens. There's no policy of secrecy within SETI. If you get a signal, and it looks interesting and you begin to think it might be the real thing, you start to call people at other observatories and say 'hey, would you check this out too?' And you find the people are writing about it on their blogs and sending emails to boyfriends and girlfriends, or tweeting or whatever. As a result, what actually happens if you get a signal is, long before it's confirmed and you know it's newsworthy, which could take days, it's already news. In 1997 we had a signal that looked good for almost a day, and by the end of that day the *NY Times* was calling me up.

What would happen next?
Well, if you really find it and confirm it's ET, the first thing is that every telescope in the world, no matter what kind of telescope, would be pointed in the direction in which you got the signal. You would try and learn as much as you could; is this a star where we have detected planets, for example. Radio telescopes could look at the signal as it changes frequency, which would tell you something about the motion of the planet, the length of their year, stuff like that.

All these instances are what would happen immediately. In terms of finding additional signals, you would probably – with the money – build much bigger antennae and go back and see if you could find any modulation on the signal, any message, because that would be very interesting. That's a very big project, however, and it would take a very large antenna. But in any case, you would know now how to look for other signals, because once you find one there's a better clue as to how to find others, and I'm sure that would happen.

Should we send a message back?
If you picked up a signal, it would be a tremendous incentive to send something back. I'm sure you couldn't stop people from doing that, a lot of people would. It doesn't trouble me, we've been sending messages into space since World War Two, and many are pretty strong, so it would just be additional information. But you could argue about what we should say, should we tell them about the bad as well as the good, and all that kind of stuff. For me it's very similar to the Indians of the Caribbean, arguing about what they should say to Columbus, should he land.

Would it be the biggest discovery of all time, in your opinion?
I once polled science journalists about this, asking them how big a story they thought it would be, and every single one of them said it would be the biggest story ever. I don't argue with them, I'm sure it would be a huge story.

If the planet is close, would a mission there be on the agenda?
Oh, I'm sure it would be seriously discussed. It would still be very hard; even with our best rockets, to go to something 50 light years away would take almost 10 million years. I think a far better scheme would be to send signals, frankly.

How confident are you we'll find something?
I bet everyone that I've spoken to about this a cup of coffee that we'll do it within two dozen years.

f_l

The fraction of total planets in our galaxy on which life exists.

×

f_i

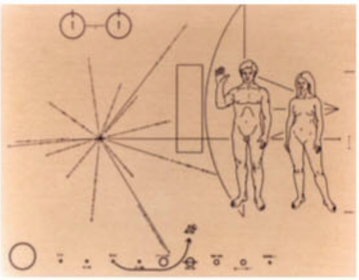
The fraction of those habitable planets where intelligent life arises.

×

f_c

The fraction of habitable planets with civilisations that develop the technology to emit signals.

×



L

The length of time any such civilisations would release these detectable signals into space.

@ Getty Images; Tobias Roetsch; Breakthrough Initiatives; ESO; JPL-Caltech; NASA; SETI Institute

YOUR QUESTIONS ANSWERED BY OUR EXPERTS

In proud association with the National Space Centre
www.spacecentre.co.uk

Sophie Allan

National Space Academy Education Officer
■ Sophie studied Astrophysics at university. She has a special interest in astrobiology and planetary science.

Zoe Baily

National Space Centre
■ Zoe holds a Master's degree in Interdisciplinary Science and loves the topic of space as it unites different disciplines.

Josh Barker

Education Team Presenter
■ Having earned a Master's in Physics and Astrophysics, Josh continues to pursue his interest in space at the National Space Centre.

Gemma Lavender

Features Editor
■ Gemma has been elected as a fellow of the Royal Astronomical Society and is a keen stargazer and telescope enthusiast on **All About Space** magazine.

DEEP SPACE

What would happen if an exoplanet crashed into a neutron star?

Shaun Peel

The exoplanet would be destroyed. The average surface temperature of a neutron star is in the order of hundreds of thousands of degrees, this would vaporise almost any material that came in contact with it. Should a planetary body in orbit around the star fall into the neutron core it would be incinerated rapidly and explosively.

The likelihood that such a body would survive this kind of event is very low. Any bodies around the star would be greatly disrupted during the supernova event with a large proportion potentially being thrown from their parent Solar System. The search for these free-floating planets is underway in an attempt to confirm these theories. **JB**

A planet would not survive an encounter with a neutron star

Make contact: @spaceanswers /AllAboutSpaceMagazine @ questions@spaceanswers.com

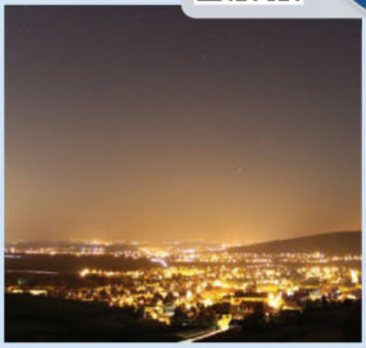
SPACE EXPLORATION

Why does water form spherical droplets in space?

David Connell

If you were to squirt a water pistol on board the ISS, the water would do something weird, congealing into a bunch of perfect spheres. The reason this happens is the condition of microgravity, which arises in free fall around the Earth. However, while the absence of substantial gravity gives rise to the spheres, there is a deeper explanation. At the boundary between liquid water and the air, the water molecules have a stronger attraction to each other than with the air molecules, creating a 'surface tension' that acts in an inward force pulling the water together. On Earth, gravity dominates this surface tension, so squirt a water pistol and the tear-shaped water droplets will spill on to the floor in a flat puddle. In space, however, without gravity, surface tension dominates and that inward force pulls the water droplet into the shape with the lowest amount of surface area possible, which is a sphere. **GL**

In a microgravity condition, water takes on a spherical shape



Light pollution is a hindrance to astronomers

ASTRONOMY

Does light pollution make astronomy impossible?

Laura Hearn

Light pollution doesn't make astronomy easy, but those under less-than-ideal conditions will find that there are still objects that can be seen - especially those that are bright.

Even from cities, targets such as the Moon and bright stars are still evident and binoculars and telescopes will show a variety of deep-sky objects such as bright galaxies and nebulae. In a light-polluted area, the unaided eye should be able to pick out objects with magnitudes of +3 or +4, rather than the +5 or +6 magnitude objects that you'd be able to see from darker sites.

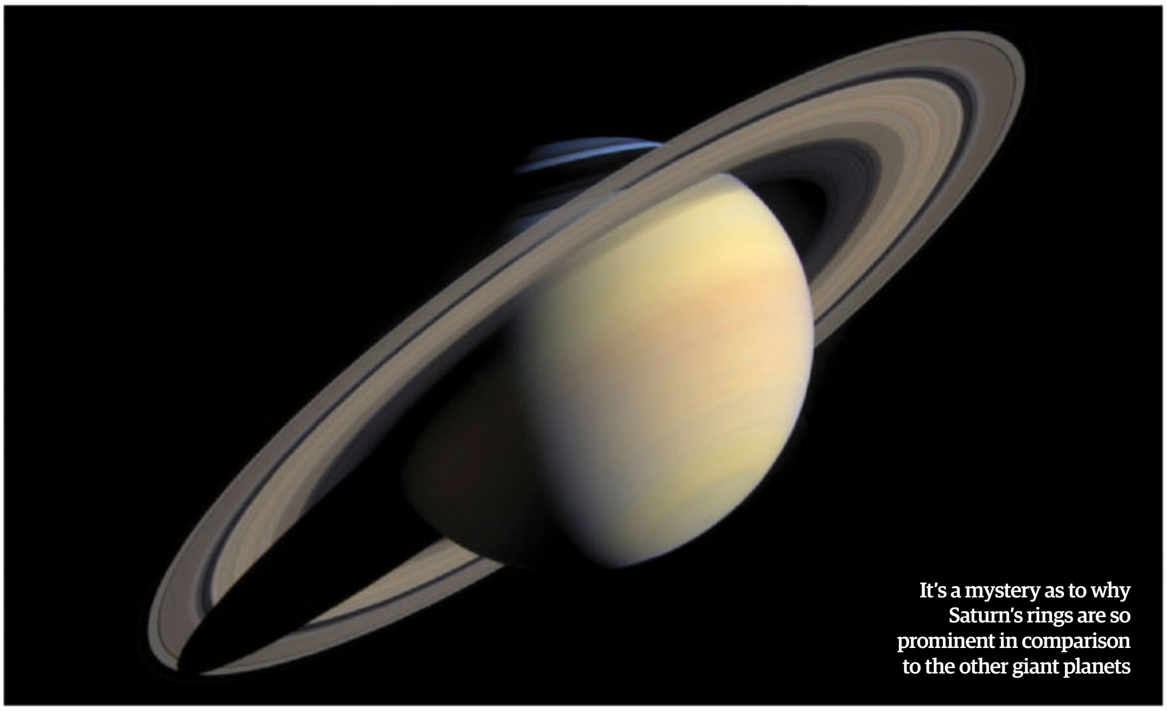
It is possible to purchase a light-pollution filter for your telescope, which blocks out the sodium light from street lamps that cause the orange haze and spoil the view, alleviating the problem. **GL**

SOLAR SYSTEM

Why does Saturn have such prominent rings?

Laura Hearn

Scientists are not yet sure exactly how the rings of Saturn came to exist and therefore why they're so much wider than those around other outer Solar System planets. Some theories suggest that, millions of years ago, one of the planet's moons might have been destroyed. Perhaps a collision with an asteroid or comet may have left only shattered remains or maybe it strayed too close to Saturn and got ripped apart. Over time the debris would have spread out to create the rings. It's possible that the rings are a constantly changing system, often being replenished as new debris comes too close. Some even think that ejecta from an icy moon could provide a source of ring material. **ZB**



It's a mystery as to why Saturn's rings are so prominent in comparison to the other giant planets

The failed stars known as brown dwarfs have been found to have vivid weather

DEEP SPACE

Can stars have weather?

David Leonard

Weather has been detected on brown dwarf stars, which are cool 'failed stars'. While brown dwarfs are still too warm for water rain or snow, infrared observations with NASA's Spitzer Space Telescope have detected mottled surfaces that have been interpreted as clouds. Not white fluffy clouds either, but at temperatures of 1,000 to 2,000 degrees Celsius (1,832 to 3,664 degrees Fahrenheit) the clouds are made of silicate (rocky) particles such as iron.

On the brown dwarf named 2M1404B, these 'rocky' clouds emit near-infrared light, making the clouds appear darker at that wavelength and the brown dwarf to appear patchy. These clouds could also rain hot sand or molten iron. Meanwhile, in one survey Spitzer also observed 44 brown dwarfs and found that half of them had brightness variations that matched what you would expect to see if they had giant storms like Jupiter's Great Red Spot dominating their atmospheres. **GL**

ASTRONOMY

You should purchase a sky atlas to help you to learn the constellations

What's the easiest way to identify constellations?

Harold Milner

The easiest way to identify constellations is to invest in a sky atlas. This could be a physical book, an online resource or even an app for your phone or tablet. A sky atlas is essentially a map of the sky. It will show you what is visible in the night sky at a particular time. This can help not only identify constellations but other celestial objects too. Depending on the time of year and your location this can range from planets and stars, to nebulae and comets.

While a sky atlas will give you a good start they will often list the 88 official constellations, which for here in the UK are mainly taken from the Greek culture. There exists a whole host of other patterns and constellations from a range of cultures that can be identified in the night sky. Some of the digital resources will already include those, however, some may take a little additional research to track down. **JB**

SPACE EXPLORATION

Could we colonise the Moon?

Joanna Gomes

Living for long periods of time on the Moon is difficult but not impossible. It is theoretically possible that we could live on the lunar surface. For the last 20 years people have been living in space in a totally different environment from the one we find on Earth. We could in theory repurpose this technology to keep us alive on the surface of the Moon.

Although the technology exists to keep people alive away from the Earth there are still a lot of issues that face long-term space travel. For example, we currently have to restock the International Space Station every few months. To compound this we have yet to find a way to counter the negative effects of low gravity. This could have huge implications on health for long stays on somewhere like the Moon. **JB**

It is possible for us to live on the lunar surface, however, there are challenges

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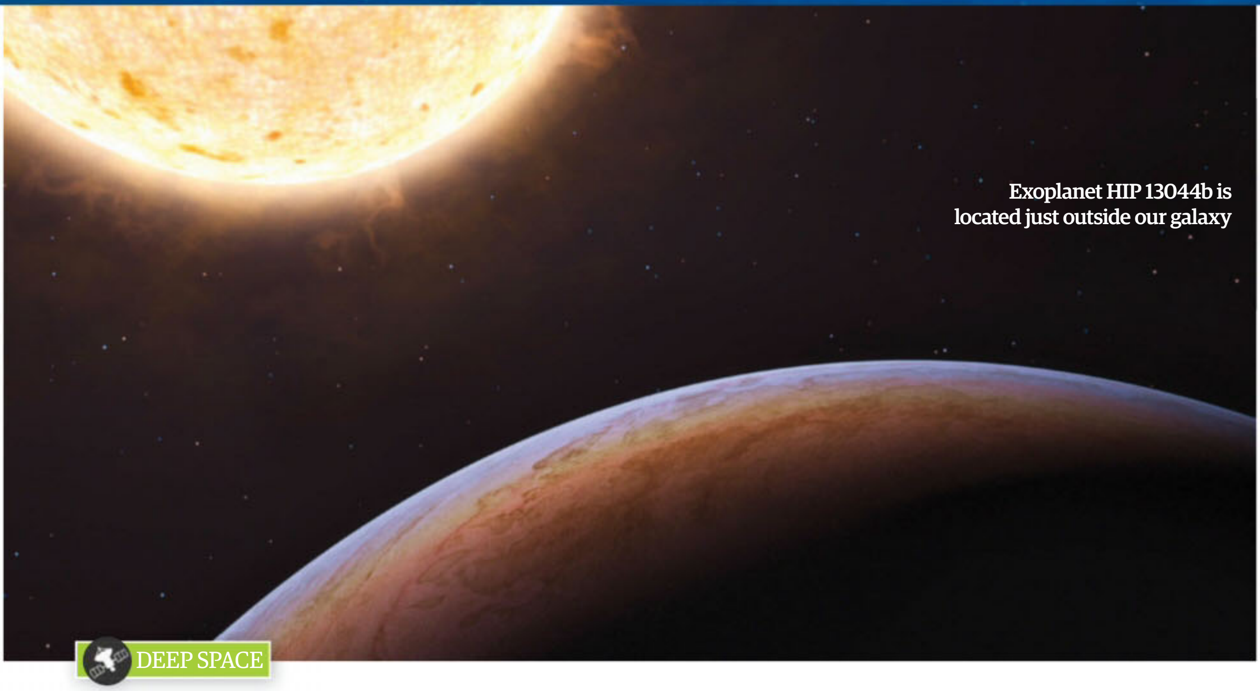


Exoplanet HIP 13044b is located just outside our galaxy

DEEP SPACE

Can we see planets in other galaxies?

Ben White

It's not possible to observe planets in other galaxies outside our own. Other galaxies are so far away and planets are so relatively small and dark compared to their stars that current telescopes are not powerful enough to see them.

So far more than 1,700 extrasolar planets have been found orbiting stars within our galaxy. There is a planet, known as HIP 13044b, which was discovered outside of our galaxy. This planet is found with a group of stars that wander just outside of the Milky Way. These stars, and therefore the exoplanet HIP 13044b, are thought to have formed in a dwarf galaxy that ended up crashing into the Milky Way. This is good proof that planets can form in other galaxies even if we can't see them. **ZB**

Our planet would become very cold and dark if it were surrounded by black holes

SOLAR SYSTEM

What would happen if Earth were surrounded by black holes?

John Leonard

The result ultimately depends on how the black holes are positioned around our planet. Regardless of setup the Earth would probably become very cold and dark. Black holes are black because their gravity is so strong that nothing can escape if it gets too close, not even light. Surrounding the Earth with black holes would mean that any energy from the Sun or other sources, stars etc, would be blocked and absorbed by the black holes.

If the black holes were set up correctly a gravitationally stable setup could be achieved that would just have the black holes orbit the Earth and absorb the energy headed this way. This would be complicated and should these sources be created the system would likely be unstable. The Earth and some of the other black holes could consume each other resulting in a larger black hole in Earth's place, the instability could cause our planet to be ejected or various other scenarios. **JB**

Quick-fire questions

@spaceanswers

What is at the edge of the Milky Way?

Our galaxy is surrounded by a halo of old stars and a layer of dark matter. Beyond this is intergalactic space.

Who was the tallest astronaut?

The tallest person to fly into space is American Jim Wetherbee, who is 193 centimetres (6 feet 4 inches) and a veteran of six Space Shuttle missions.

What is a harvest Moon?

These are big, orange-tinted full Moons. They occur close to the autumnal equinox, which marks the first day of autumn. Harvest Moons take on their orange colour when they are close to the horizon.

Who was the first British person in space?

Helen Sharman, who visited the Mir Space Station when she flew on-board a Russian Soyuz capsule in May 1991.

Can we see the Great Wall of China from space?

This is a myth. Although the Great Wall of China is over 8,850 kilometres (5,500 miles) long, it is too narrow to pick out with the naked eye.

What does a star diagonal do?

Refracting telescopes direct the light to the eyepiece at the end of the telescope, but this can be at an awkward angle to view through. A star diagonal is an angled mirror or prism that redirects the light by 90 degrees to a more comfortable angle for the observer to look through.

Does space smell of anything?

While some astronauts have reported a sweet metallic scent in space, others have experienced the smell of seared meat and welding fumes.

Quick-fire questions

@spaceanswers

Can I see the Triangulum Galaxy without a telescope?

Yes - just - if you have very keen eyesight and an extremely dark observing site. You will stand a better chance with binoculars or a four or six-inch telescope.

What is the smallest exoplanet that has been found so far?

The smallest exoplanet known is Kepler-37b, which is 3,860 kilometres (2,400 miles) across, which is only slightly larger than Earth's Moon.

What is the largest optical telescope?

Currently it is the Gran Telescopio Canarias, in the Canary Islands, which is 10.4 metres (34 feet) across, but it'll soon be overtaken by the Thirty Meter Telescope in Hawaii and the 39-metre (128-foot) European Extremely Large Telescope in Chile.

How far does Earth's atmosphere extend?

The outer 'layer' of our planet's atmosphere is called the mesosphere. This extends around 85 kilometres (53 miles) above Earth's atmosphere.

Could a white hole exist?

While some scientists believe that the reverse of a black hole does exist, we are yet to find any evidence for them. For now, however, they are considered as a hypothetical object.

What will happen when the Sun dies?

Currently halfway through its life, the Sun will run out of hydrogen in its core and the nuclear fusion that is keeping it 'alive' will come to an end. It will then swell into a red giant, puffing off its layers, leaving a hot white dwarf at its centre.

Scott Kelly (right) will spend a year in space while his twin brother remains on Earth

SPACE EXPLORATION

How long can a person live in space?

Jamie Roberts

Nowadays astronauts normally spend six months in space at any one time although some missions can last longer. The record for the longest single spaceflight is 437 days and 18 hours. Theoretically it would be possible for us to live in space for much longer provided we developed a spacecraft with all the provisions to support life. If we became almost perfectly efficient at recycling resources such as oxygen, water and food it might be possible to live in space indefinitely.

However, we currently do not know the full long-term effects of living in space on the human body. Hopefully future missions and experiments with astronauts will help us find out more. **ZB**

Don't expect Hubble-standard images when looking through your telescope

ASTRONOMY

Why can't I see colourful nebulae through my telescope?

John Jenkins

We are often shown fantastic nebulae, splashing their technicolour displays across the cosmos, however looking out into the night sky yields a seemingly monochrome landscape. The reason we don't see these delightful cosmic jewels is a result of the huge distances associated with space. These objects are so far away that either they appear so small the colours blend together or the light has reduced in intensity so much we can't make out the additional detail. To counteract this we rely on the assistance of technology. Telescopes and other devices can magnify our view of the night sky. By magnifying what we see we can see these objects in greater detail, which can begin to give us an insight into just how beautiful these objects can be. **JB**

DEEP SPACE

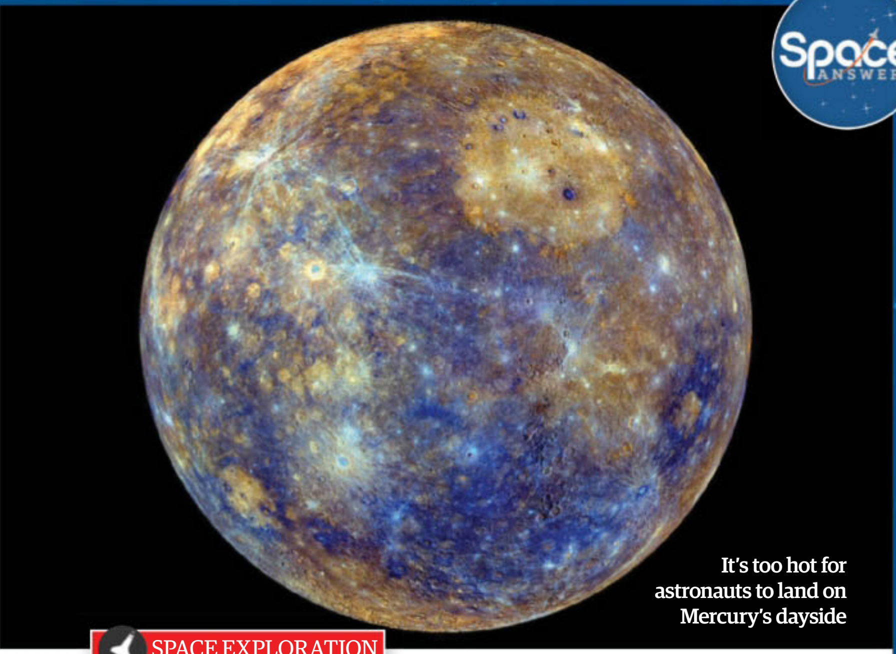
Red dwarfs are in abundance in our galaxy

What are the most common stars in the Milky Way?

Ron Williams

Generally, the smaller the star, the more common it is. So red dwarfs are more common than stars with the mass of the Sun, and Sun-like stars are more common than the enormous stars that explode as supernovae. It is estimated that 85 per cent of the stars in the Milky Way galaxy are red dwarfs, although because they are dim and cool, not many of them are bright enough to be seen in the night sky without using a large telescope.

The reason smaller stars outnumber larger, more massive stars is because of how the giant clouds of molecular gas that form stars fragment. Stars are born when a pocket of gas in this cloud begins to collapse and condense. It's easier for smaller pockets to condense than larger ones, meaning we get more small stars. **SA**


It's too hot for astronauts to land on Mercury's dayside

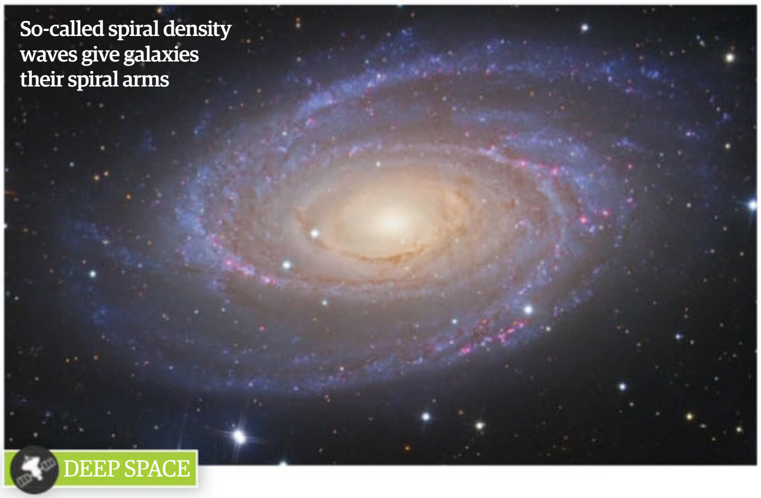
SPACE EXPLORATION

Is Mercury too hot for us to land on?

Tim Brookes

The surface temperature on the dayside of Mercury reaches a sweltering 427 degrees Celsius (801 degrees Fahrenheit), so astronauts couldn't land where they can see the Sun from the surface. Mercury is a strange planet though. It rotates very slowly, three times for every two orbits (Mercury takes 88 days to complete one orbit, or year, around the Sun), which means that the hemisphere that is facing the Sun stays there for a long time, while the hemisphere facing away, where it is night, gets as cold as -173 degrees Celsius (-279 degrees Fahrenheit).

Astronauts could land there, protected from the cold by their spacesuits, but if they are clever there is a zone that runs around the planet like a ring, on the terminator between the night and day. Here the temperature could be as low as 10 or 20 degrees Celsius (50 or 68 degrees Fahrenheit). This zone would move around the planet as Mercury rotates. If their base was mobile, astronauts could keep up with this moderate zone. **GL**


So-called spiral density waves give galaxies their spiral arms

DEEP SPACE

How do galaxies get their spiral arms?

James Lane

A phenomena known as a density wave creates this eye-catching feature of a spiral galaxy. Spiral arms in galaxies are not rigid, permanent structures, but are analogous to a traffic jam on the motorway – when a car slows down, all the cars behind it have to slow down too, causing a traffic jam. As the cars at the front move on, the traffic jam moves further down the road as more cars join the back of the jam. This is a manifestation of a phenomenon called a density wave and the same thing happens in galaxies. When stars move around a galaxy, they may be slowed by the gravity of a nearby massive gas cloud, causing a backlog of stars behind them, creating the denser spiral arms. Gas clumps up in the spiral arms, causing bursts of new star formation. The actual spiral shape of the density waves occurs because the stars move in ellipses, not circles, around the galaxy and that the alignment of these ellipses changes with distance from the centre of a galaxy in a spirograph pattern. **GL**

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Next Issue

JUPITER THE PLANET KILLER

Was the king of the Solar System responsible for dispatching super-Earths?

HOW STARS DETONATE

Witness the powerful explosions that mark the end of a stellar life

EXTRAORDINARY EXOPLANETS

Meet the rarest alien worlds in the universe

WHAT NASA HAS DONE FOR YOU

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STARGAZER

GUIDES AND ADVICE TO GET STARTED IN AMATEUR ASTRONOMY

In this issue...

74 **Become an astronomer** Your essential guide to starting out in astronomy

84 **Observe Comet Catalina** How to get the best views of the comet of the year

86 **What's in the sky?** Find the most spectacular night-time objects

88 **Me and my telescope** We showcase your best astrophotography images

92 **Astronomy kit reviews** The latest astronomy gear and telescopes tested

Become an ASTRONOMER

Part 1

If the starry skies inspire you with wonder and curiosity then you have the 'right stuff' to become an astronomer

Written by **Peter Grego**

Humans have been awed by the night skies for countless millennia. We know so much more about the universe than our ancestors, but the same visceral feelings about the vast, silent majesty of the cosmos sweep through our senses.

A wealth of objects and phenomena delight the night-sky viewer. Some objects, like the stars, star patterns and constellations, are permanent fixtures in the cosmic tapestry, acting as guideposts to understanding and finding one's way around the heavens. Other objects, like the Moon and planets, move along a highway through the constellations and appear to change over time. A few phenomena, like comets, meteors and the northern lights, are relatively fleeting but spectacular sights. Some sky events can be predicted with great accuracy, while others spring wonderful visual surprises.

There are enough sights in the night skies to keep the astronomer enthralled for a lifetime. By probing the universe further using binoculars or telescopes, astronomers eager to explore the cosmos are capable of revealing a staggering panorama beyond Earth.

Moreover, new technology in the form of high-resolution electronic cameras, in conjunction with computer-controlled telescopes, enables far more of the universe to be observed than the 'eye at the eyepiece' alone can take in.

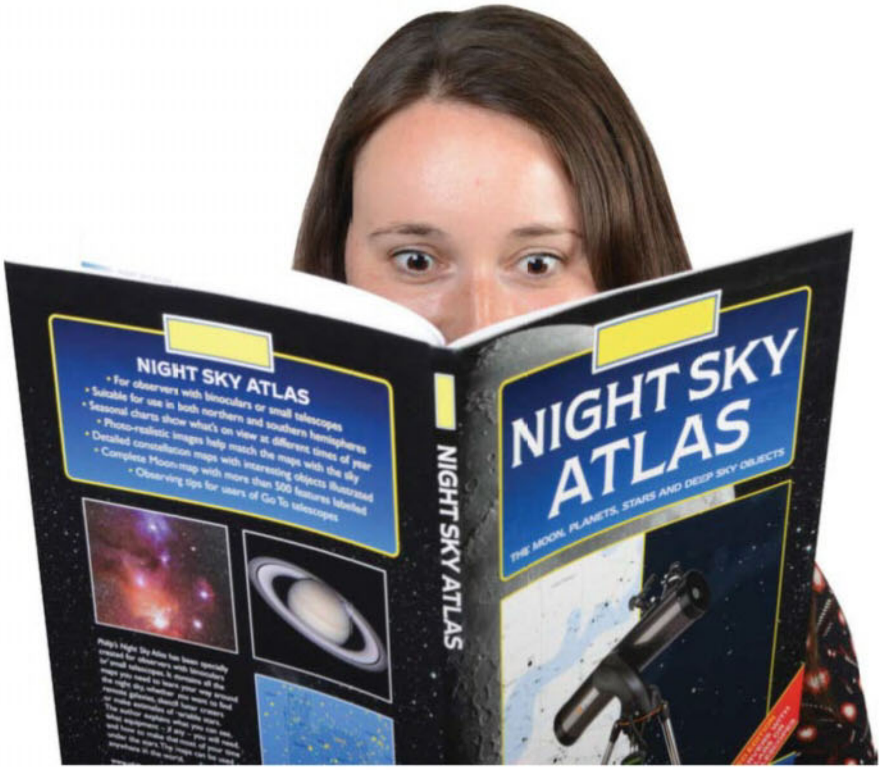
Step 1

Understanding the night sky

Knowing how the heavens work is essential before you get started in astronomy

Learning the basics is key to being able to maximise your enjoyment of astronomy. Being able to find individual objects – whether they're permanent fixtures within constellations, such as double stars, star clusters or nebulae, or transitory visitors such as planets, comets or asteroids – depends on knowing where to look. It's a big sky.

At first, it may seem a daunting task to learn the layout of the skies, the positions of the main constellations and the often tongue-twisting names of the brightest stars. Time is on your side – there's no rush, and the thrill of being able to identify star patterns and individual stars remains with you forever and is a skill that you can pass on to others.



Your best route to success is to join a local astronomical society where your learning curve will be enhanced by being in the company of more experienced sky-watchers. Whether you're learning from other astronomers or going solo, you need to be standing beneath the starry sky with some form of star map, be it printed or on a handheld computer. Most astronomers learn enough to get by comfortably and enjoy their own particular form of astronomy.

Constellations are constructs of the human imagination, many of them derived from ancient myths and legends. In a 'join the dots' fashion, some of these ancient patterns actually resemble the entities they are meant to portray; some are incredibly large and sprawling, while others appear to simply fill in the gaps in this giant celestial jigsaw puzzle. We still use this imaginary patchwork of star patterns because they break up the night sky – which is essentially a random scattering of stars – into manageable sections, enabling objects to be referred to and located with relative ease.

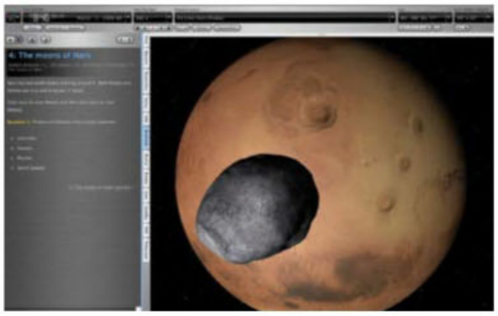
Each constellation contains an assortment of stars of varying brightness. The brightest stars have their own names, mostly derived from the Arabic. Letters of the Greek alphabet are also used to identify the brightest stars in each constellation. For example, the brightest star in Taurus (the Bull) is Alpha Tauri (also known as Aldebaran), the second brightest is Beta Tauri (also known as Elnath), then Gamma Tauri, and so on.

Spread about, in and among the 'official' constellations, there are recognisable groupings of bright stars known as 'asterisms'. These take the form of distinct, easily identifiable shapes, perhaps the most famous of which is the Plough or Big Dipper, which is made up of stars within the constellation of Ursa Major (the Great Bear). Dozens of asterisms can be found in the night sky, and some of their stars can be used as convenient pointers to the location of other stars and constellations.

Another legacy from our ancient past is the notion that the stars and constellations are fixed inside a distant, all-encompassing sphere that surrounds our planet. Even though we have long known that we're actually looking at objects covering a vast range of distances from Earth, astronomers still refer to this sphere – known as the celestial sphere – for convenience. Just as the Earth is crossed by an imaginary system of latitude and longitude to enable terrestrial seafarers and explorers to pinpoint their position, the celestial sphere has an equivalent system of imaginary lines known as 'declination' (which is abbreviated 'dec'; equivalent to latitude) and 'right ascension' (which is abbreviated 'RA';

Top five planetarium software

Get to know the night sky from the comfort of your sofa

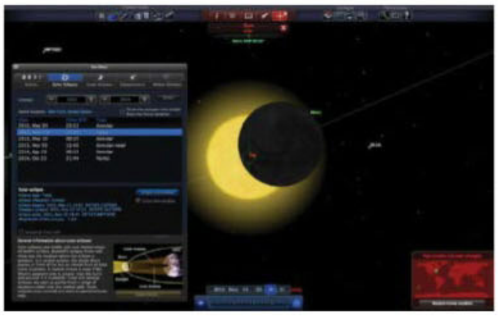


Starry Night

A richly featured planetarium program with great graphics and a user-friendly interface, fully customisable for the individual user. Various versions are available.

Cost: $49.95 (approx £35) for CSAP version

Available for: Windows/Mac



Redshift

A highly capable planetarium program, Redshift's drop-down interface requires some familiarisation to get the most out of it. On handheld computers it can be used to locate and identify objects live beneath the stars.

Cost: From £7.99 / $9.99 (depending on version)

Available for: Windows/iOS/Android

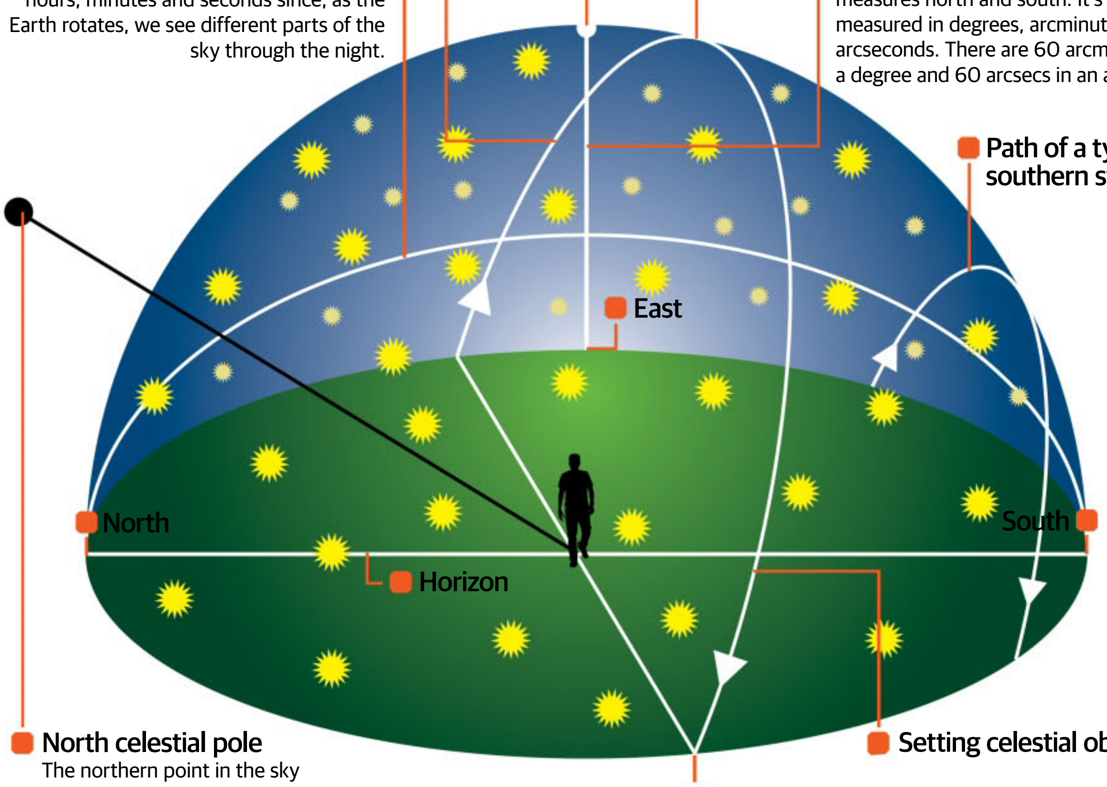
equivalent to longitude) that allows celestial explorers to precisely zero-in on objects in the night sky. Parallel lines of declination are measured up to +90 degrees (north) and -90 degrees (south) from the celestial equator, while great circles of right ascension are measured from 0 to 24 hours around the celestial equator. Each degree of declination and each hour of right ascension is split into 60 arcminutes and each arcminute is further divided into 60 arcseconds.

Since our planet revolves on its axis inside the celestial sphere, it follows that the terrestrial poles point to the celestial poles, while the celestial equator is always directly above Earth's equator.

From the latitude of London (52 degrees north), the north celestial pole is 52 degrees above the northern horizon, a point conveniently occupied by Polaris, the Pole Star. As Earth turns from west to east, the celestial sphere appears to rotate around the celestial pole in an anticlockwise manner. An area of sky surrounding the north celestial pole is continually above the horizon - from London, this 'circumpolar' region includes everything north of +38 degrees dec on the celestial sphere. Stars between +38 degrees and -38 degrees dec rise in the east and set in the west (those on the celestial equator rising due east and setting due west), while everything south of -38 degrees dec down to the south celestial pole can never be seen from London. During the course of the year, the entire celestial sphere makes a complete circuit around the Earth, so viewing the constellations depends upon both the time of night and the date on which you're viewing the skies.

The sky around you

As Earth rotates, the stars rise and set, tracing arcs at various heights above the horizon



Celestial equator
A great circle on the celestial sphere that lies in the same plane as the Earth's terrestrial equator and is tilted at roughly 23 degrees to the ecliptic.

Rising celestial objects

Right ascension
Right ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. Measured in hours, minutes and seconds since, as the Earth rotates, we see different parts of the sky through the night.

Declination
How high an object will rise in the sky. Like Earth's latitude, declination measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcmins in a degree and 60 arcsecs in an arcmin.

Path of a typical southern star

North celestial pole
The northern point in the sky about which all of the stars seem to rotate – around the North Star, also known as Polaris.

Setting celestial objects

SkyMap Online

SkyMap Online is a free web app that comes with a full set of features to help both casual stargazers and amateur astronomers to explore and locate objects in the night sky.

Cost: Free from www.sky-map.org
Available for: Windows/Mac

SkySafari

With its delightful graphics, this app is fully customisable and easy to use, a very instructive and powerful app to use in the field that opens up the majesty of the night skies.

Cost: From £2.29 / $2.99 (depending on version)
Available for: Mac/iOS/Android

Stellarium

A free open-source planetarium program with sumptuous graphics. Easy to use, Stellarium can be used on handheld computers in the field to pinpoint thousands of celestial targets.

Cost: From free (but depending on platform)
Available for: Windows/Mac/iOS/Linux/Android

Step 2

Navigating the night sky

Using nothing but your eyes and a good star map, that seeming confusion of stars above your head will begin to take shape

Finding your bearings beneath the night sky is an essential first step to becoming familiar with it.

It's important that you begin by viewing the night skies from a relatively dark location, free from direct sources of light, such as kitchen windows, the glare of 'security lights' and streetlights. Your eyes need to adapt to the darkness so that you can see faint objects, otherwise you'll be restricted to seeing just a handful of the brightest objects. Some people can find a convenient dark spot in their garden where much of the sky can be seen, while some find themselves in such a hopelessly 'light-polluted' spot that there's no option other than to venture away from their home in order to enjoy darker skies.

You don't need to refer to detailed celestial coordinates, RA and dec, to find and identify the brightest stars and constellations – all that's required is a basic map of the stars with which you can compare the naked-eye view.

Now that you've found Polaris and the two brightest circumpolar constellations you can extend your exploration further afield by using a star map – be it a manual planisphere, star chart, printout from a computer program – or a 'live interactive view' on a handheld computer. If you're using a paper chart, make sure that you have a red torch to illuminate it – low-level red light doesn't greatly affect your adaptation to the dark.

If you are using a handheld computer such as an iPhone, turn the device's brightness down to such an extent that the brightness of its screen isn't overwhelming but can be read in the dark.

Understanding magnitudes

All celestial objects are allocated a brightness known as 'apparent magnitude', indicating how bright they appear. The scale works 'backwards', in that the lower the magnitude number, the brighter the object. So, for example, a star of magnitude 0 is brighter than one of magnitude +1, while an object of magnitude -1 is brighter than one of magnitude 0. Each jump in magnitude corresponds to a 2.5 times increase in apparent brightness.

The Sun

The full Moon

The crescent Moon

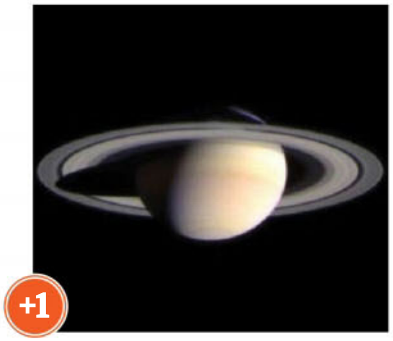
Venus

Jupiter

Sirius (the brightest star)

Capella (the sixth brightest star)

All of the above are easily seen when they are well above the horizon, even from a light-polluted urban environment.



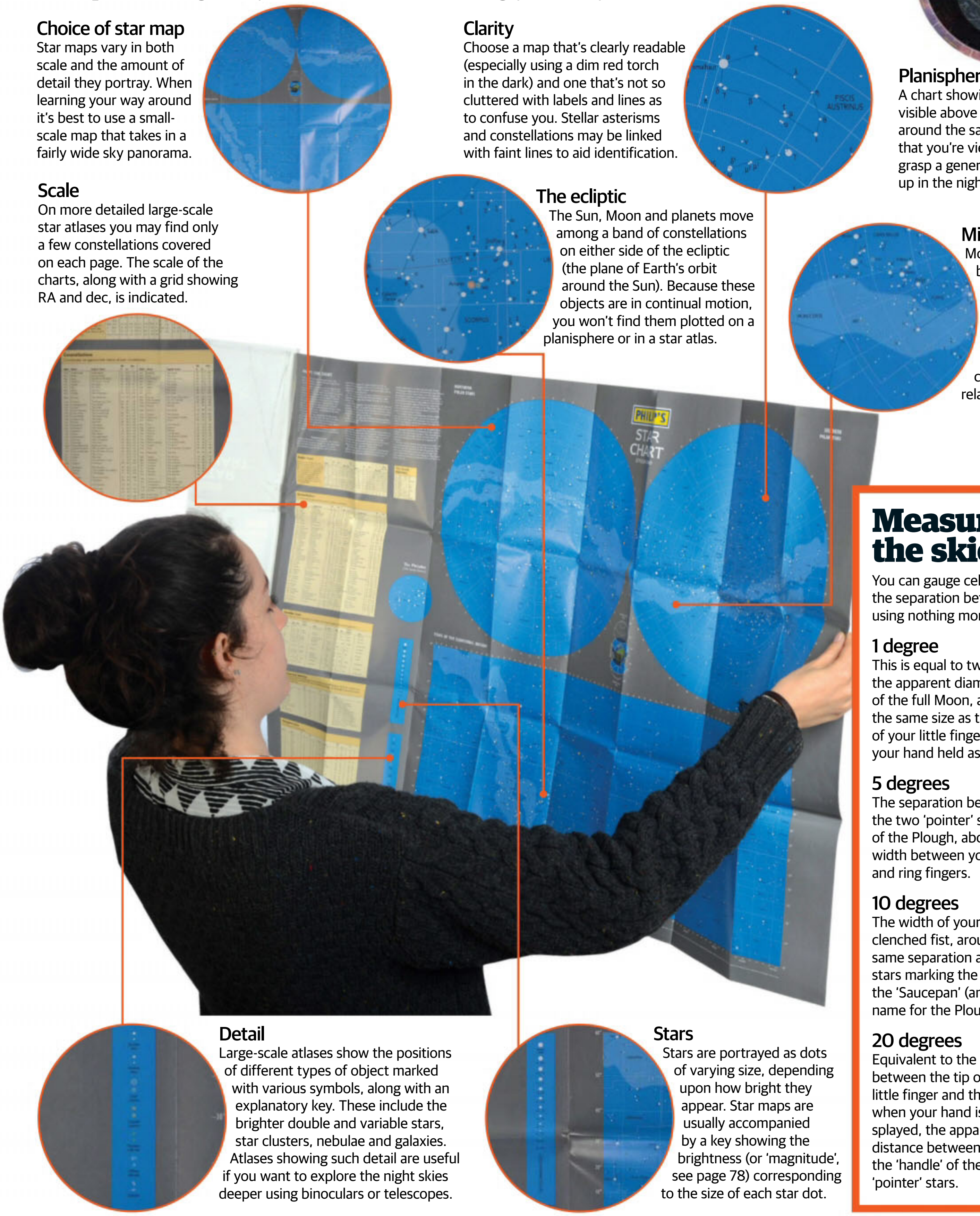
Saturn

Polaris (the 50th brightest star)

Objects fainter than Polaris prove more difficult to see from urban locations. From the suburbs you'll most likely consider it a very good night if you see objects down to magnitude +4 with the naked eye. The faintest objects visible without an optical aid from a really dark site are around magnitude +6 – providing your eyesight is excellent.

How to use a sky map

A map of the night sky is invaluable for finding your way around



Choice of star map

Star maps vary in both scale and the amount of detail they portray. When learning your way around it's best to use a small-scale map that takes in a fairly wide sky panorama.

Scale

On more detailed large-scale star atlases you may find only a few constellations covered on each page. The scale of the charts, along with a grid showing RA and dec, is indicated.

Clarity

Choose a map that's clearly readable (especially using a dim red torch in the dark) and one that's not so cluttered with labels and lines as to confuse you. Stellar asterisms and constellations may be linked with faint lines to aid identification.

The ecliptic

The Sun, Moon and planets move among a band of constellations on either side of the ecliptic (the plane of Earth's orbit around the Sun). Because these objects are in continual motion, you won't find them plotted on a planisphere or in a star atlas.

Planisphere

A chart showing the whole sky visible above your location at around the same time and date that you're viewing will allow you to grasp a general overview of what's up in the night sky.

Milky Way

Most star maps feature a broad, slightly irregular shaded band that represents the glow of distant stars in our own galaxy. Known as the Milky Way, it can only be seen from relatively dark sites.

Detail

Large-scale atlases show the positions of different types of object marked with various symbols, along with an explanatory key. These include the brighter double and variable stars, star clusters, nebulae and galaxies. Atlases showing such detail are useful if you want to explore the night skies deeper using binoculars or telescopes.

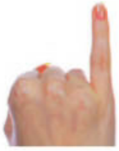
Stars

Stars are portrayed as dots of varying size, depending upon how bright they appear. Star maps are usually accompanied by a key showing the brightness (or 'magnitude', see page 78) corresponding to the size of each star dot.

Measuring the skies

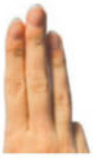
You can gauge celestial angles – such as the separation between two stars – by using nothing more than your hand.

1 degree



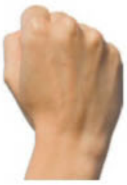
This is equal to twice the apparent diameter of the full Moon, around the same size as the tip of your little finger (with your hand held as far away as possible).

5 degrees



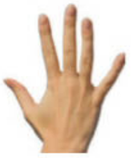
The separation between the two 'pointer' stars of the Plough, about the width between your index and ring fingers.

10 degrees



The width of your clenched fist, around the same separation as the stars marking the rim of the 'Saucepan' (another name for the Plough).

20 degrees



Equivalent to the width between the tip of your little finger and thumb when your hand is fully splayed, the apparent distance between the second star in the 'handle' of the 'Saucepan' and the 'pointer' stars.

Step 3

What to observe on your first night

Now that you're familiar with the night sky, you are ready to begin a fuss-free evening of stargazing

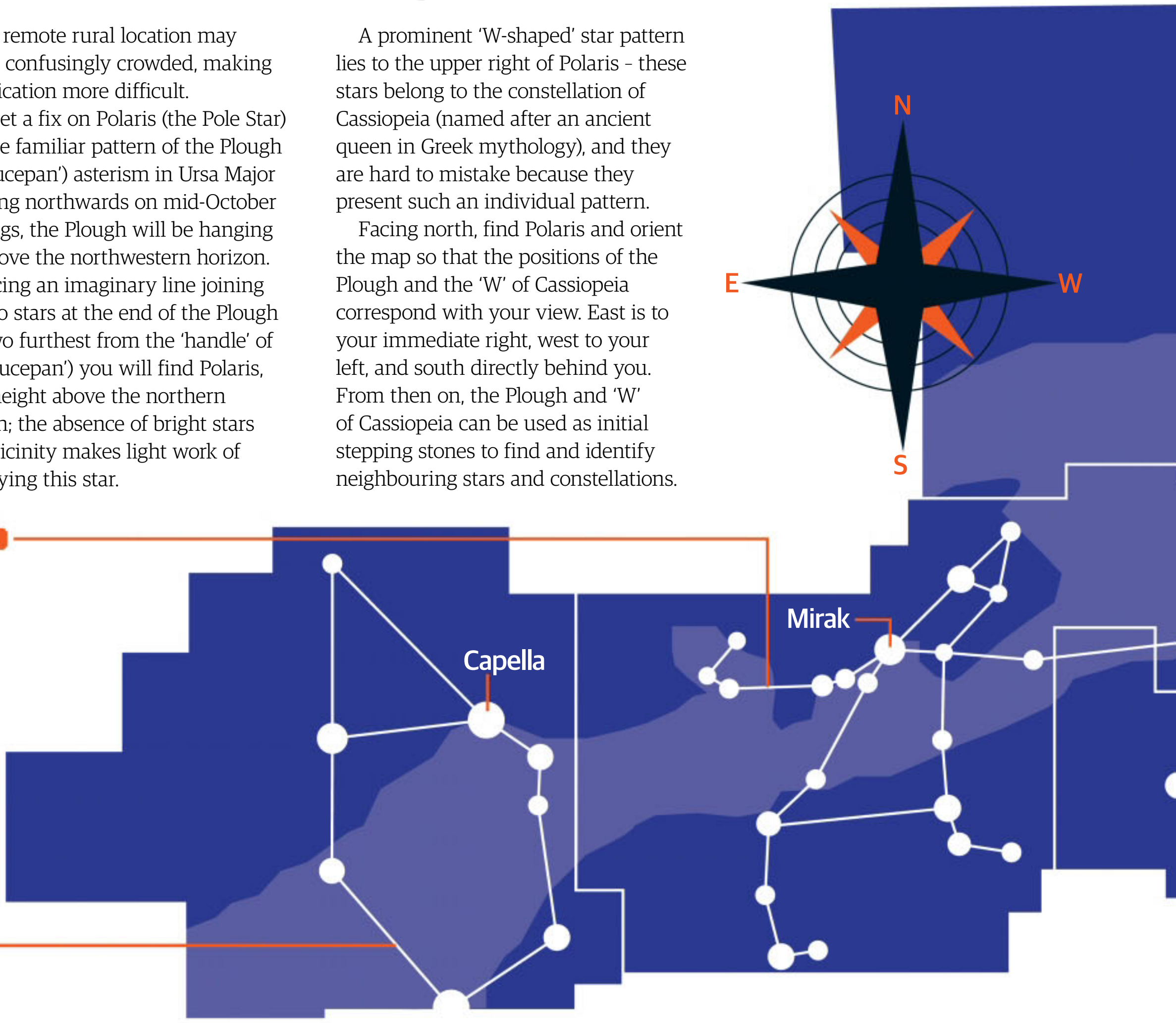
The darkness of the night sky at your viewing location determines the number of stars that you will be able to observe.

From an urban area, with its many streetlights and other sources of illumination lighting up the atmosphere, the sky never looks completely dark, and you'll only be able to see the brightest objects. However, from a dark country location you'll see many more stars - perhaps more than a small star map will actually depict. Being under a light-polluted sky can have its advantages when you come to learning the basics, because a truly dark night sky seen from a remote rural location may appear confusingly crowded, making identification more difficult.

To get a fix on Polaris (the Pole Star) find the familiar pattern of the Plough (or 'Saucepan') asterism in Ursa Major - looking northwards on mid-October evenings, the Plough will be hanging low above the northwestern horizon. By tracing an imaginary line joining the two stars at the end of the Plough (the two furthest from the 'handle' of the 'Saucepan') you will find Polaris, a fair height above the northern horizon; the absence of bright stars in its vicinity makes light work of identifying this star.

A prominent 'W-shaped' star pattern lies to the upper right of Polaris - these stars belong to the constellation of Cassiopeia (named after an ancient queen in Greek mythology), and they are hard to mistake because they present such an individual pattern.

Facing north, find Polaris and orient the map so that the positions of the Plough and the 'W' of Cassiopeia correspond with your view. East is to your immediate right, west to your left, and south directly behind you. From then on, the Plough and 'W' of Cassiopeia can be used as initial stepping stones to find and identify neighbouring stars and constellations.

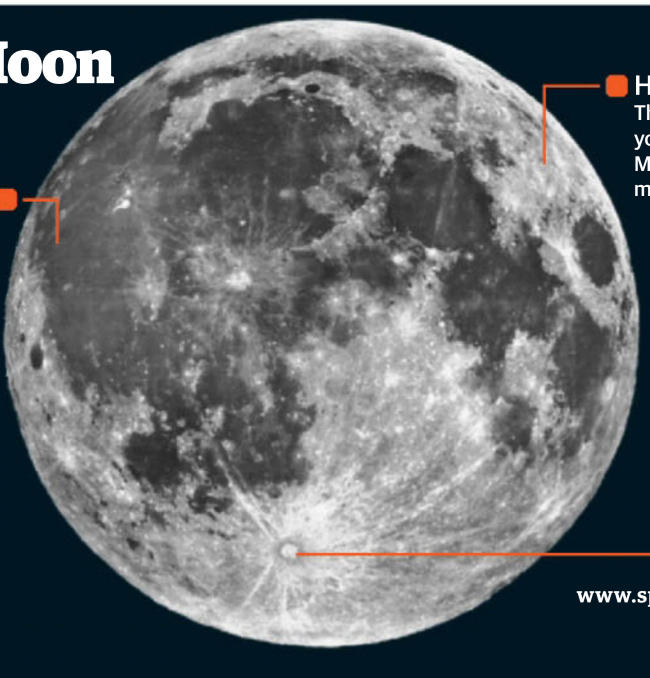


Perseus (a legendary hero) can be found above Auriga in the northeastern skies. It contains numerous bright stars sprinkled along a section of the Milky Way, and is one of the loveliest areas to scan with binoculars. Binoculars will also reveal a beautiful double star cluster located directly between the brightest star in Perseus (Mirfak, magnitude +1.8) and the middle star in the 'W' of Cassiopeia.

Auriga (the Charioteer) is rising in the northeast and can be identified by its prominent bright star Capella (magnitude 0), the sixth brightest star in the sky.

Top sights to see on the Moon

Our lunar companion is a glorious object, with some of its features visible without an optical aid



The lunar 'seas' Visible as dark patches on the Moon, the 'seas' are actually large areas of lava that spread over big asteroid impact craters billions of years ago.

Earthshine When the Moon is a narrow crescent phase in the dark twilight skies, you'll notice a faint glow of its unilluminated side. This is caused by sunlight reflected from Earth onto the Moon's night side.

Highlands The brighter areas you can see on the Moon are the lunar mountain ranges.

Craters Impact basins pepper the Moon's surface. In particular, the crater Tycho can be seen with the naked eye.

Pre-dawn naked-eye planets

Venus

Visible: Throughout October

Rises: 4am in the east

The second planet from the Sun is unmistakably bright with the naked eye and dazzling through binoculars. A telescope is needed to make out Venus as a little planetary disc.

Jupiter

Visible: Throughout October

Rises: 4am in the east

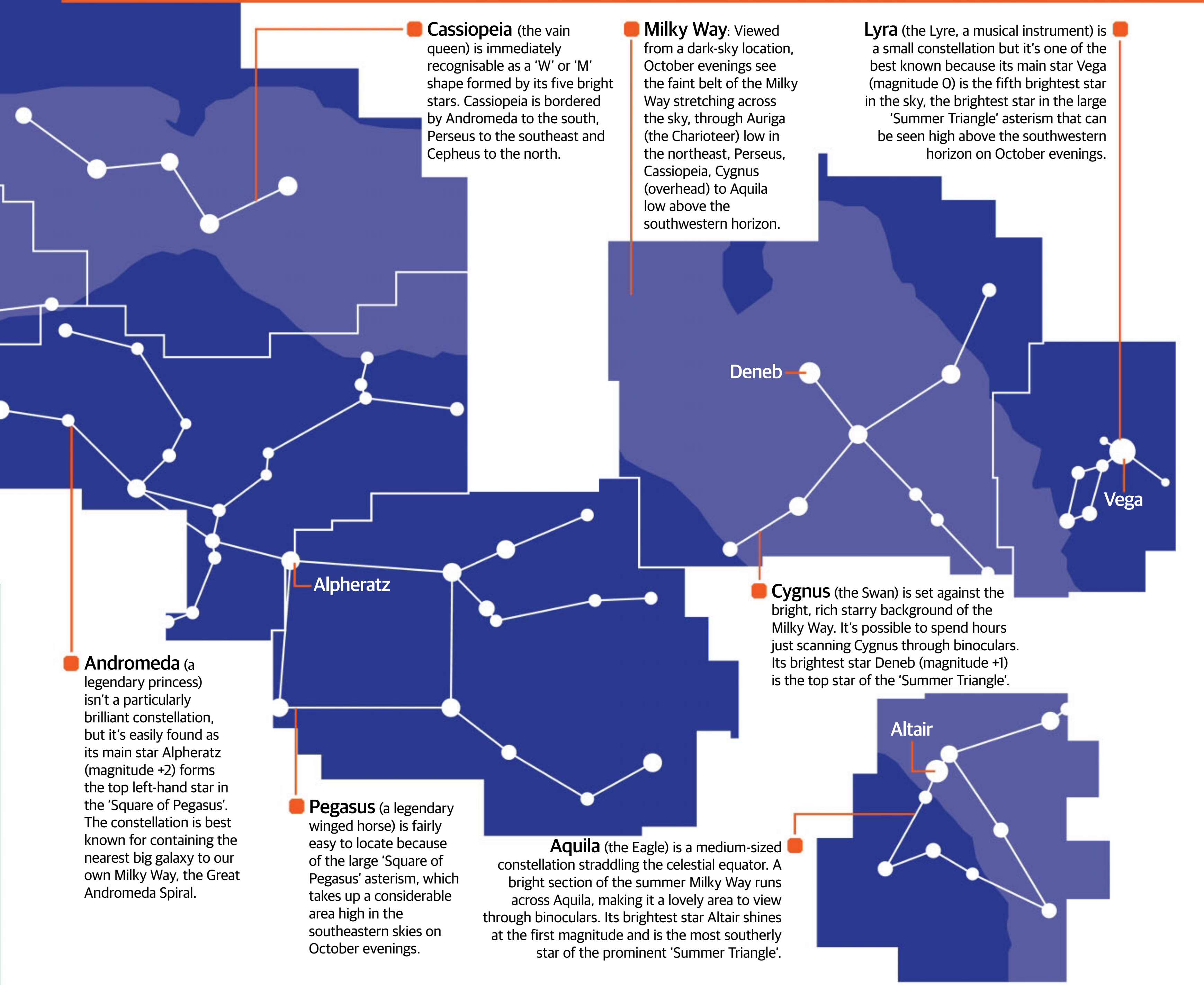
Located very close to Venus on 26 October. Although Jupiter isn't as bright as Venus, it is brighter than any other star. Binoculars will show the planet as a small disc closely surrounded by its four brightest moons.

Mars

Visible: Throughout October

Rises: 4am in the east

Located very close to Jupiter, it's closest on 18 October when they are less than half a degree apart. Mars is considerably dimmer than Jupiter but it can easily be seen as a little orange point of light through binoculars.



Cassiopeia (the vain queen) is immediately recognisable as a 'W' or 'M' shape formed by its five bright stars. Cassiopeia is bordered by Andromeda to the south, Perseus to the southeast and Cepheus to the north.

Milky Way: Viewed from a dark-sky location, October evenings see the faint belt of the Milky Way stretching across the sky, through Auriga (the Charioteer) low in the northeast, Perseus, Cassiopeia, Cygnus (overhead) to Aquila low above the southwestern horizon.

Lyra (the Lyre, a musical instrument) is a small constellation but it's one of the best known because its main star Vega (magnitude 0) is the fifth brightest star in the sky, the brightest star in the large 'Summer Triangle' asterism that can be seen high above the southwestern horizon on October evenings.

Cygnus (the Swan) is set against the bright, rich starry background of the Milky Way. It's possible to spend hours just scanning Cygnus through binoculars. Its brightest star Deneb (magnitude +1) is the top star of the 'Summer Triangle'.

Andromeda (a legendary princess) isn't a particularly brilliant constellation, but it's easily found as its main star Alpheratz (magnitude +2) forms the top left-hand star in the 'Square of Pegasus'. The constellation is best known for containing the nearest big galaxy to our own Milky Way, the Great Andromeda Spiral.

Pegasus (a legendary winged horse) is fairly easy to locate because of the large 'Square of Pegasus' asterism, which takes up a considerable area high in the southeastern skies on October evenings.

Aquila (the Eagle) is a medium-sized constellation straddling the celestial equator. A bright section of the summer Milky Way runs across Aquila, making it a lovely area to view through binoculars. Its brightest star Altair shines at the first magnitude and is the most southerly star of the prominent 'Summer Triangle'.

Step 4

Choosing your first telescope

Picking a telescope can be a challenge. **All About Space** finds the one that's right for you

Telescopes gather and focus light using precisely shaped mirrors and lenses (or a combination of both). The larger the telescope's main mirror or lens, the more light is gathered and the more detail you will be able to see - this is very important in the realm of astronomy, since many celestial objects are rather small and faint. Eyepieces are used to magnify the image focused by the main mirror or lens.

Most astronomers begin with a small, relatively unsophisticated telescope and upgrade to larger instruments as their budget allows. For a beginner, there are a number of advantages in starting with a small telescope: they are lightweight, portable, and to some extent expendable. These days you can purchase a good small telescope for just a few tens of pounds - but remember to buy it from a reputable astronomical retailer (such as those who advertise in this magazine) in order to ensure quality and best value for money. You'll find that good retailers are only too willing to answer any specific questions that you have about making the right choice tailored to your own budget, requirements and expectations.

There are three basic types of telescope. Reflectors use a main mirror to gather and focus light; refractors use an objective lens, while catadioptrics use a main mirror and a lens of the same diameter. All three kinds of instrument have their own 'sub-species' based on their particular optical design.

For example, the most basic type of reflector is the Newtonian design, which uses a main mirror and a small secondary mirror, which diverts the light at right angles to the eyepiece through the top end of the telescope. Refractors use a specially designed lens, a sandwiched double lens known as an achromat, focusing light down the tube to an eyepiece at the bottom. Because of the way that they bend light, achromats always introduce a certain amount of false colour, mostly seen as coloured fringes around the edge of the Moon and bright planets; this is, however, pretty unobtrusive. The most expensive refractors are apochromats, which produce pin-sharp, fully corrected images - they usually cost five to ten times more than achromats. Catadioptrics come in two main forms - the Schmidt-Cassegrain and the Maksutov. Aperture for aperture, these are more costly than Newtonian reflectors.

During your observations, you will find that objects in the night sky appear to slowly drift as the Earth rotates. The simplest form of mount for any telescope is the manual alt-azimuth variety, which requires the user to occasionally nudge the telescope (up and down or from side to side) so that the celestial object remains in the field of view. Computer-driven alt-azimuth mounts can be set up so that you get a 'hands-free' experience - some have a GoTo facility where objects can be found automatically by the telescope's computer. German equatorial mounts are aligned with the celestial pole.

Instruments for beginners

A range of devices are available for those just breaking into stargazing

Achromatic refractor

Price: Start at around £50 to £100 / $75 to $150

Best for:
- ✓General night-sky viewing
- ✓Low-high magnification views of the Moon and planets

Pros:
- 👍 Wide range available
- 👍 Low maintenance, optics are factory set and don't require adjusting
- 👍 Portable
- 👍 Mount can be upgraded as needs and budget allow

Cons:
- 👎 Requires a sturdy tripod and stable mount
- 👎 Some degree of false colour is often visible

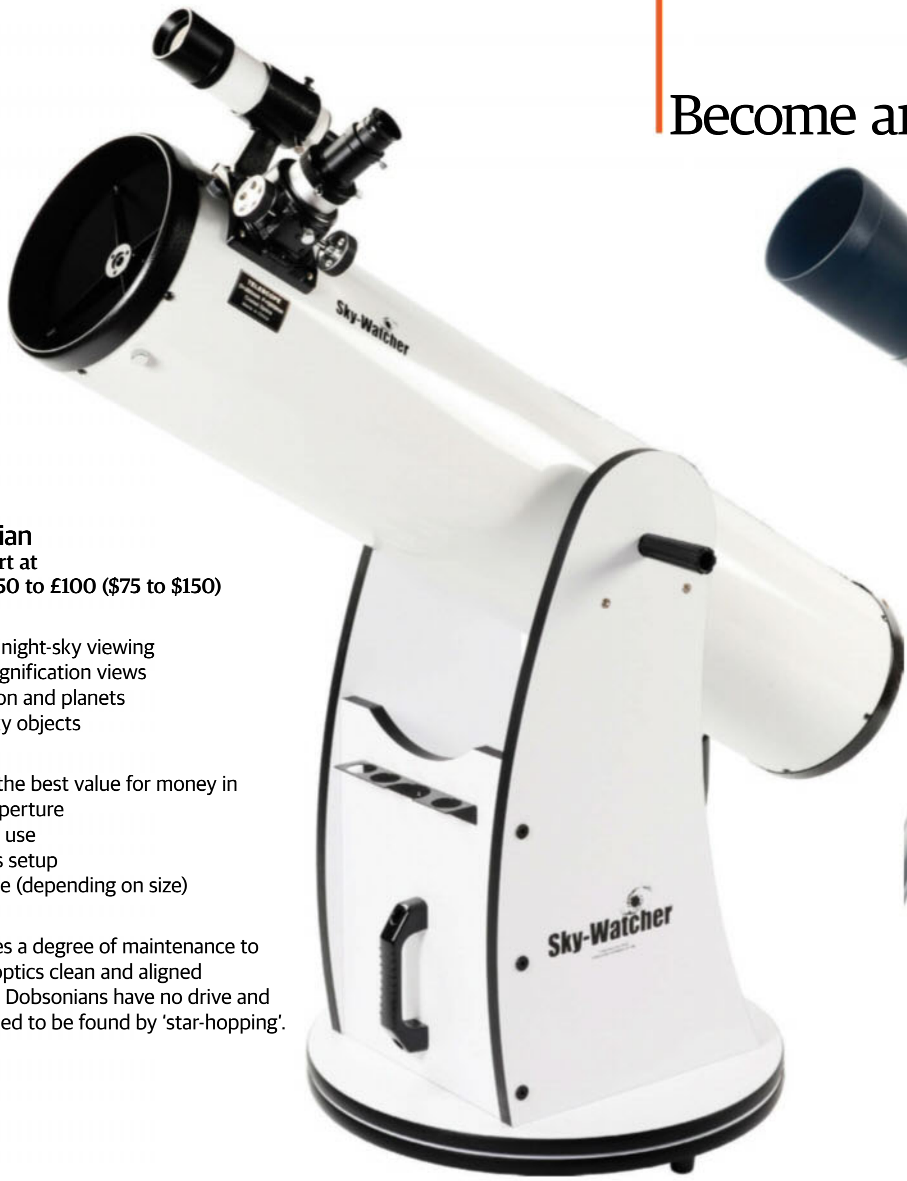
Maksutov-Cassegrain

Price: Start at around £250 / $380

Best for:
- ✓General night-sky viewing
- ✓High-magnification views of the Moon and planets
- ✓Deep-sky objects

Pros:
- 👍 Come with computer-controlled drives and GoTo facilities

Cons:
- 👎 Can be fairly heavy
- 👎 Expensive



Dobsonian

Price: Start at around £50 to £100 ($75 to $150)

Best for:

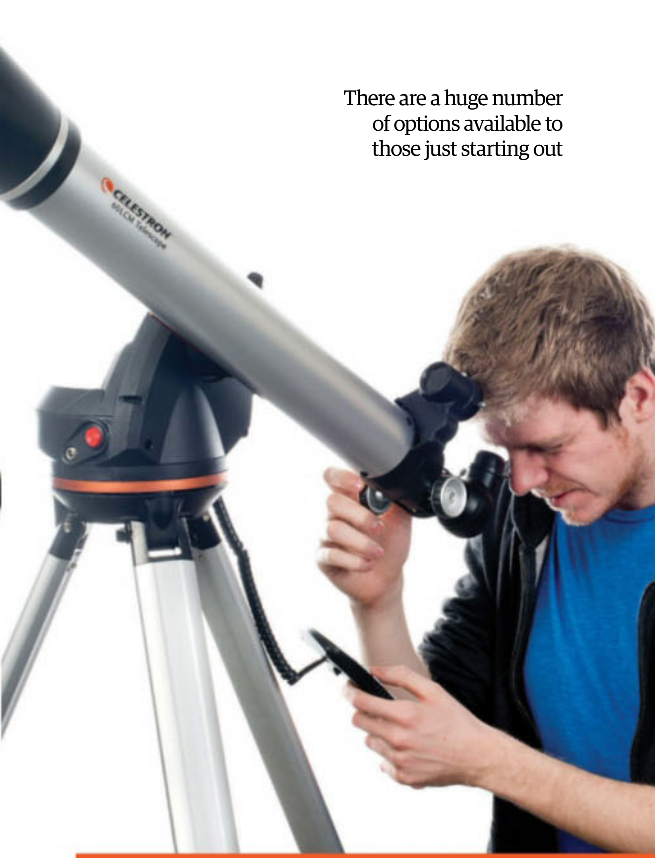
✔General night-sky viewing
✔Low-magnification views of the Moon and planets
✔Deep-sky objects

Pros:

👍 Offers the best value for money in terms of aperture
👍 Easy to use
👍 No-fuss setup
👍 Portable (depending on size)

Cons:

👎 Requires a degree of maintenance to keep the optics clean and aligned
👎 Manual Dobsonians have no drive and objects need to be found by 'star-hopping'.



There are a huge number of options available to those just starting out

Schmidt-Cassegrain

Price: Start at around £250 / $380

Best for:

✔General night-sky viewing
✔Low-magnification views of the Moon and planets
✔Deep-sky objects

Pros:

👍 Come with computer-controlled drives and GoTo facilities

Cons:

👎 Can be fairly heavy
👎 Need occasional adjustment to keep optics precisely aligned
👎 Expensive

Essential telescope buying tips

✔ Buy from a reputable astronomical retailer or second-hand from a trustworthy astronomer.

✔ Choice is a little easier if you have an idea about what kind of astronomy you'd like to pursue - be it lunar, planetary or deep-sky observing.

✔ Browse the web for user reviews.

✔ Ask someone who knows about telescopes for their opinion and/or recommendations.

✔ Can the telescope be upgraded in future? Upgrades include setting it up on a better tripod or mount, adding computer control, better eyepieces and finderscope.

✔ Substantial accessories are provided with the telescope.

✔ Good portability and easy to set up.

NEXT ISSUE:
Become an astronomer PART TWO

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How to view Comet Catalina

Be prepared for a potential comet of the year with our essential guide

Comets are notoriously fickle night-sky objects. Some are given high expectations of putting on a good show and fail to deliver, whereas others, originally thought to be unremarkable, may suddenly flare up and astound everyone. In general, though, it's really difficult to say just how a comet is going to behave and making predictions for Comet Catalina can be just as dangerous. However, it does seem to be brightening steadily and all being well, should become a naked-eye object in the next few weeks.

Comet C/2013 US10 Catalina, to give it its proper designation, travels from southern to Northern Hemisphere skies over the course of October through to December and should keep brightening as it does so. At the beginning of October, the comet had a visibility of magnitude +6, which meant that it was just visible to the naked eye from a dark-sky site. Catalina can be found amid the stars of the Southern Hemisphere constellation of Centaurus as it heads steadily northwards. By this time, it is thought that the comet will have brightened enough to make easy naked-eye viewing.

It should, however, be easy to spot in binoculars. The best time to catch it, if you live in the Southern Hemisphere, is mid-evening, looking south-southwest. It quickly drops in elevation as the month progresses and by mid-month it will be fairly low down and in the late twilight. By the end of October it will be found on the border of Hydra and Libra and becoming much harder to see in the evening twilight. A small telescope at low power should also show it well, but please make sure that the Sun has fully set before you start sweeping the night sky for the comet.

The comet is due for its encounter with the Sun, that is its closest approach, on 15 November, so the best time to catch it is as early in the month as you can; within a matter of days it will be down too low near the horizon to see. After early November, it will be too near to the Sun for safe observation. If Catalina survives its solar encounter, and unfortunately many comets do not, then after this date it will become a Northern Hemisphere object. The comet will then be moving swiftly through the early morning skies past the constellation of Virgo and heading toward the bright star Arcturus in Boötes (the Herdsman) on 1 January 2016. All the while, it is expected to grow in brightness.

It's difficult to say for sure, but through 7x50 or 10x50 binoculars, the comet will most likely look like a fuzzy ball of light, hopefully with a distinct tail; in fact maybe two tails, as images taken of Catalina so far have shown the comet has two tails, giving it a noticeable 'V' shape. This is not uncommon with comets and is often very beautiful. If you're using a small telescope, it will be best to keep the magnification as low as possible to give the widest field of view, as comets can take up quite a bit of sky. Do look out for any hint of colour you might detect. Already, images have shown a greenish tint to the comet.

Is this going to be the comet of the century? That remains to be seen, but so far Catalina has given us every indication that it will be impressive, by most cometary standards anyway, so fingers crossed that it survives its brush with the Sun in mid-November. The best time to see it in the Northern Hemisphere will be through the early hours of the morning through the month of December.

5 essential tips and tricks for comet hunting

Get a star map

A good star chart is necessary for comet hunting, so you can find it with ease. Alternatively, purchasing a GoTo telescope will take the fuss out of finding a comet.

Use binoculars or a telescope

To view a comet comfortably, you should ensure you have 10x50 binoculars at least or, if it's a particularly faint comet, a good-sized telescope.

Make use of filters

Filters, such as the ultra-high contrast (UHC) and 'Swan Band' varieties that are able to pick out faint objects, can be really useful when it comes to viewing comets.

Observe without the Moon

Moonlight will wash out faint targets, so comet hunting is best carried out during a new Moon or during times when it is below the horizon.

Have patience

In general, comets are known to be faint and incredibly tricky to spot. However, perseverance is often rewarded, so prepare for a long night of viewing.

How to view Comet Catalina

Images, like this one taken by astronomer Ian Sharp, show the comet with two tails and a greenish tint

1

1 October 2015

Catalina in Centaurus

Right ascension: 14h 37m 18.0s
Declination: -38° 13' 06.2"
Magnitude: +6.10
Minimum optical aid: 10x50 binoculars

Catalina is now in the constellation of Centaurus and moving northwards. It's easily visible in binoculars.

2

1 November 2015

Catalina encounters the Sun

Right ascension: 14h 21m 56.8s
Declination: -19° 00' 09.1"
Magnitude: +4.76
Minimum optical aid: Not visible

The comet has its closest approach to the Sun and moves from the southern to northern hemisphere.

3

1 December 2015

A bright morning object

Right ascension: 14h 18m 58.3s (J2000)
Declination: -11° 18' 55.9" (J2000)
Magnitude: +4.74
Minimum optical aid: Naked eye

Comet Catalina is now visible in the early hours for observers in the northern hemisphere.

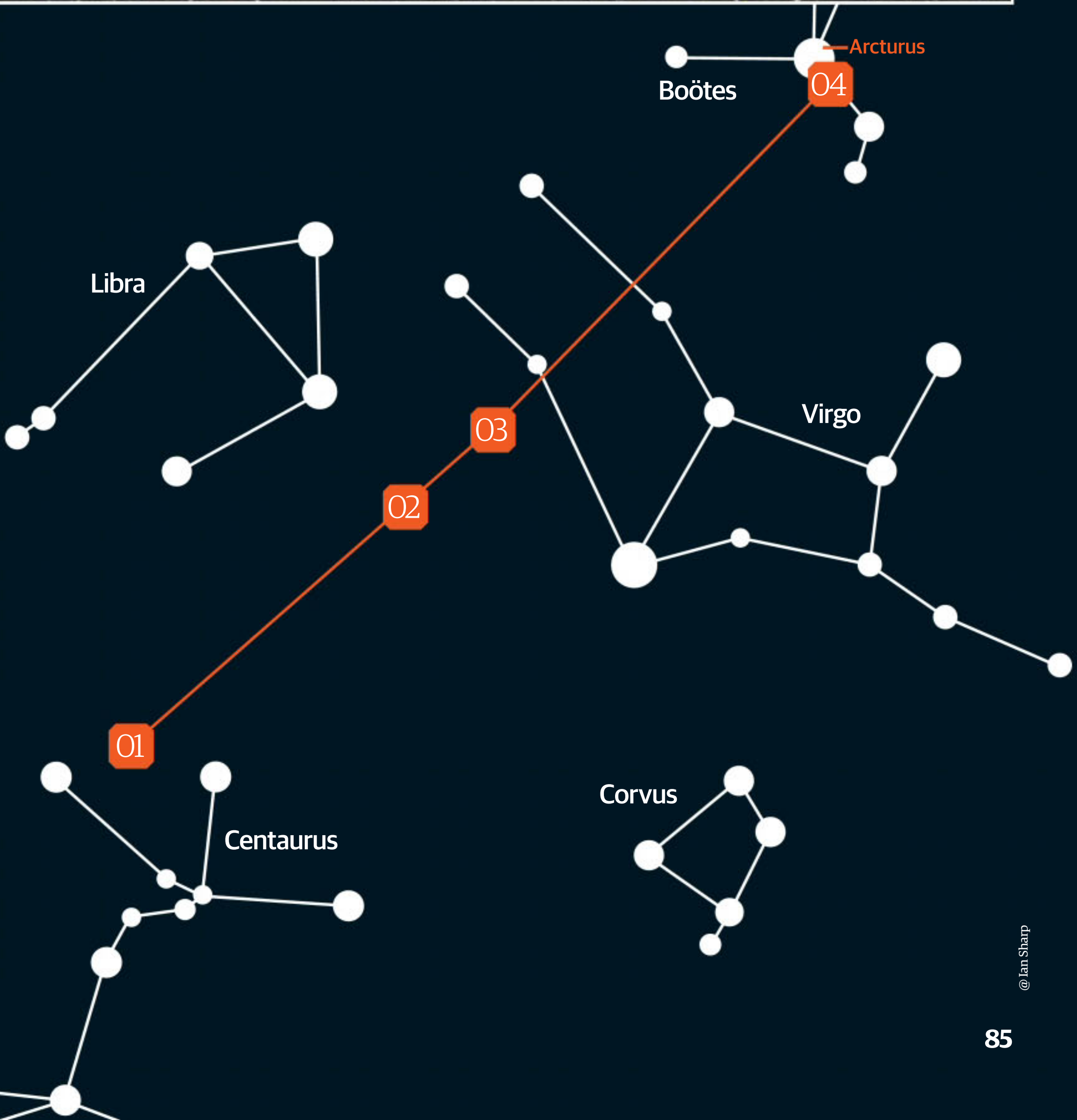
4

1 January 2016

Catalina and Arcturus

Right ascension: 14h 13m 50.8s
Declination: +18° 48' 30.7"
Magnitude: +4.89
Minimum optical aid: Naked eye

Catalina appears to swing by the bright star Arcturus. This will be a dramatic sight.

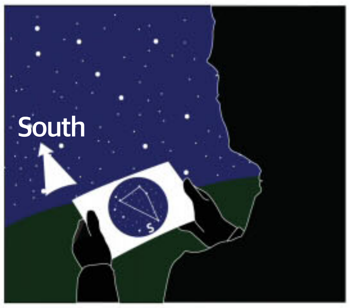


@ Ian Sharp

What's in the sky?

The constellations show us that autumn is on its way and there are plenty of deep-sky wonders to keep you busy

Using the sky chart



Please note that this chart is for midnight mid-month and set for 45° latitude north or south respectively.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

The Pleiades, M45

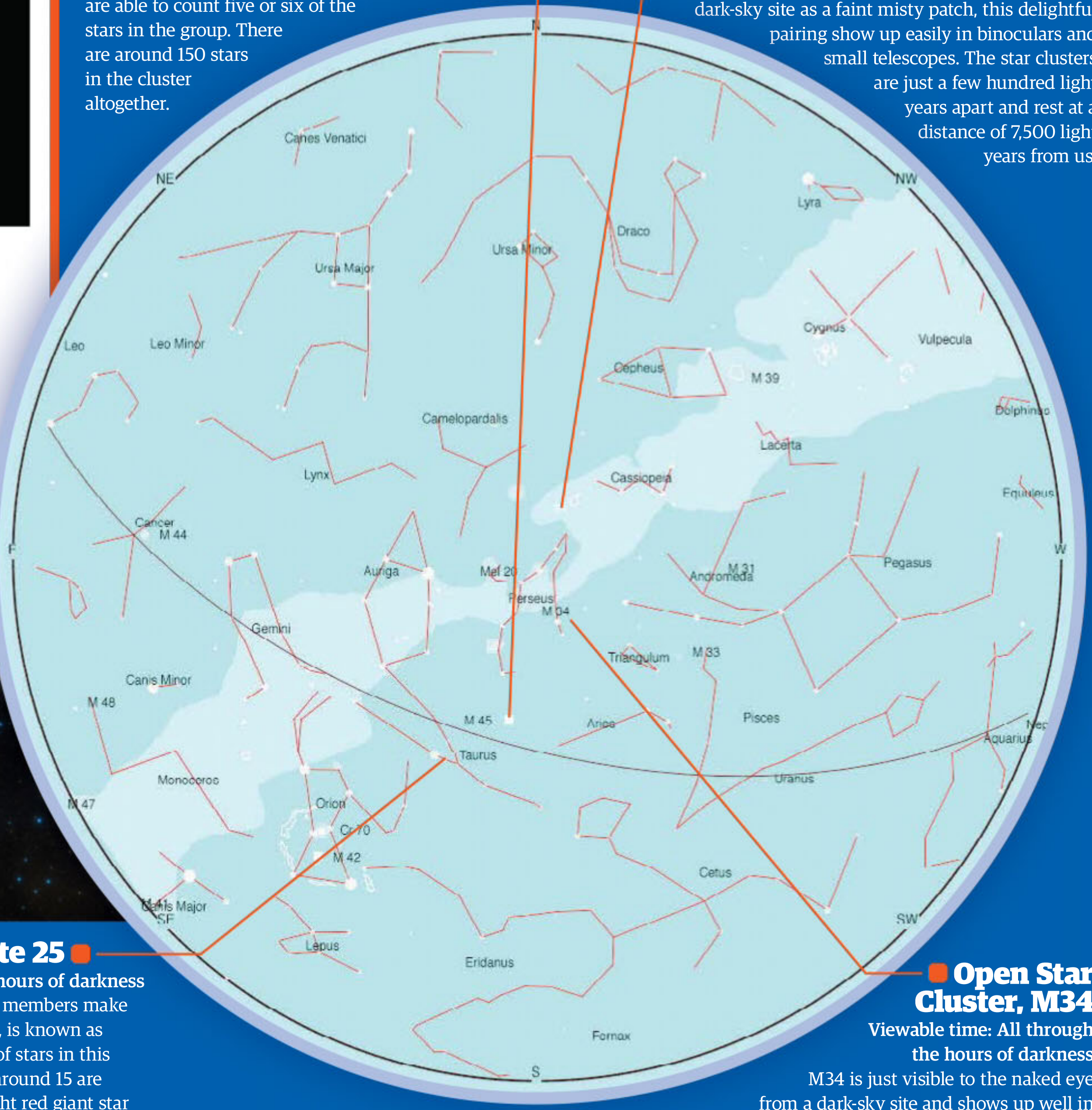
Viewable time: All through the hours of darkness

Hailed as one of the most famous star clusters of all, the Pleiades is an open star cluster visible to the naked eye, found just off the shoulder of Taurus. Even from the moderately light-polluted skies over a town, many are able to count five or six of the stars in the group. There are around 150 stars in the cluster altogether.

The Double Cluster, NGC 884 & 869

Viewable time: All through the hours of darkness

Located in Perseus, these two star clusters are often described as the 'Sword Handle' of Perseus. Visible to the naked eye from the favourable conditions of a dark-sky site as a faint misty patch, this delightful pairing show up easily in binoculars and small telescopes. The star clusters are just a few hundred light years apart and rest at a distance of 7,500 light years from us.



Northern Hemisphere

The Hyades, Melotte 25

Viewable time: All through the hours of darkness

This star cluster, whose brightest members make up the 'V'-shaped head of Taurus, is known as the Hyades. There are hundreds of stars in this astronomer's favourite, but only around 15 are visible to the naked eye. The bright red giant star Aldebaran, which serves as the fiery 'eye' of the Bull, appears to sit within the cluster but it is not connected, as it is much closer to us than the Hyades, which rests 153 light years away from Earth.

Open Star Cluster, M34

Viewable time: All through the hours of darkness

M34 is just visible to the naked eye from a dark-sky site and shows up well in binoculars of at least 10x50 magnification, while a small telescope will start to resolve many of the 400 stars in the group. M34 is around 1,500 light years away from us and it's thought that the stars are around 250 million years old.

Southern Hemisphere

Pearl Cluster, NGC 3766

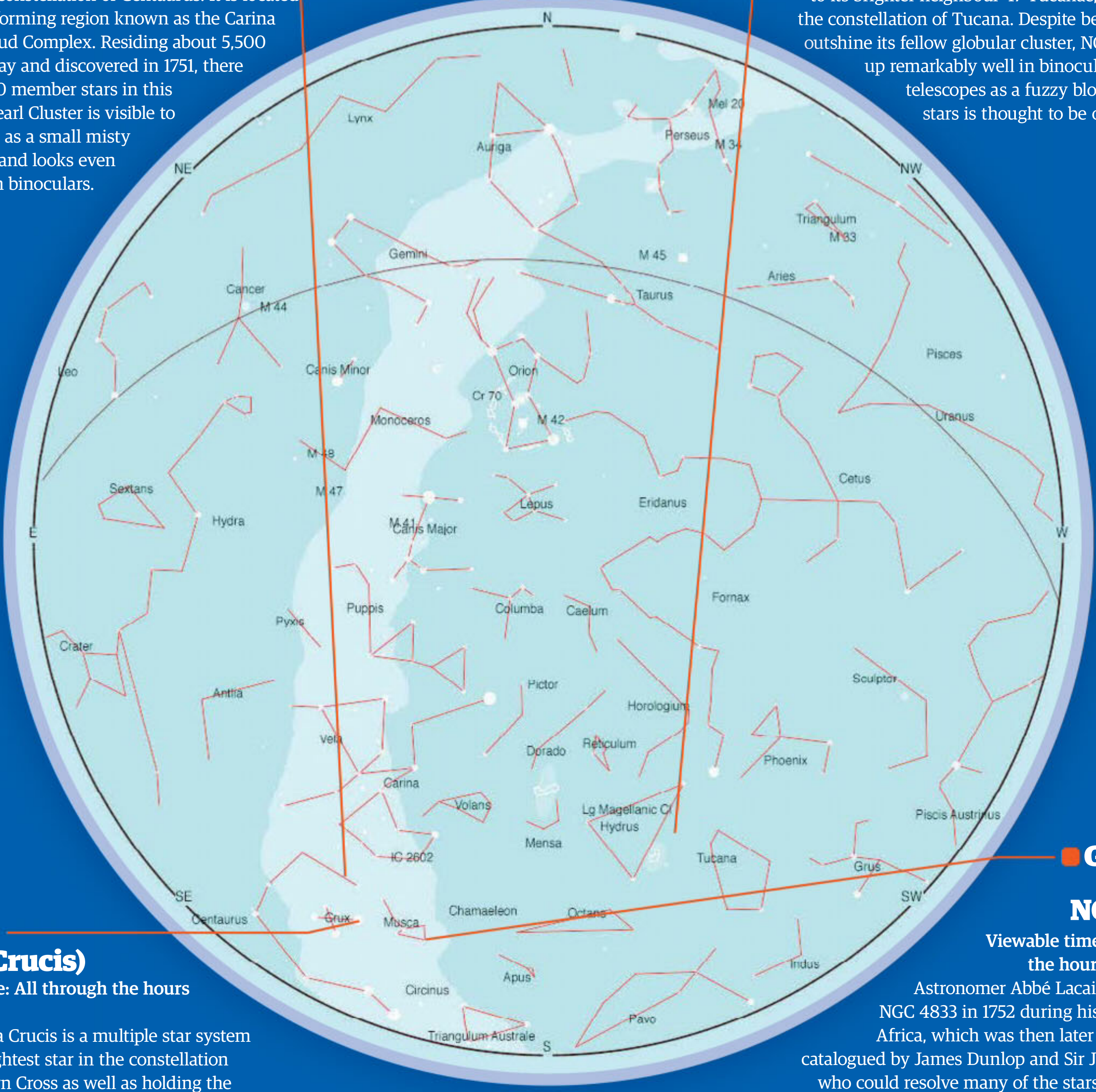
Viewable time: All through the hours of darkness

This lovely open star cluster in the southern Milky Way is in the constellation of Centaurus. It is located in a vast star-forming region known as the Carina Molecular Cloud Complex. Residing about 5,500 light years away and discovered in 1751, there are around 130 member stars in this cluster. The Pearl Cluster is visible to the naked eye as a small misty patch of light and looks even better through binoculars.

Globular Cluster, NGC 362

Viewable time: Through most of the hours of darkness

This often-overlooked globular star cluster, largely due to its brighter neighbour 47 Tucanae, is situated in the constellation of Tucana. Despite being unable to outshine its fellow globular cluster, NGC 362 shows up remarkably well in binoculars and small telescopes as a fuzzy blob. This ball of stars is thought to be over 10 billion years old.



Acrux (Alpha Crucis)

Viewable time: All through the hours of darkness

The star Alpha Crucis is a multiple star system and is the brightest star in the constellation of the Southern Cross as well as holding the record for being the 13th brightest star in the entire night sky. Two of the system's blue B-type stars are visually resolvable.

Globular Cluster, NGC 4833

Viewable time: All through the hours of darkness

Astronomer Abbé Lacaille discovered NGC 4833 in 1752 during his trip to South Africa, which was then later observed and catalogued by James Dunlop and Sir John Herschel, who could resolve many of the stars in the group. NGC 4833 rests 21,200 light years from us in the constellation of Musca and is thought to be one of the oldest globular clusters at about 12.5 billion years.

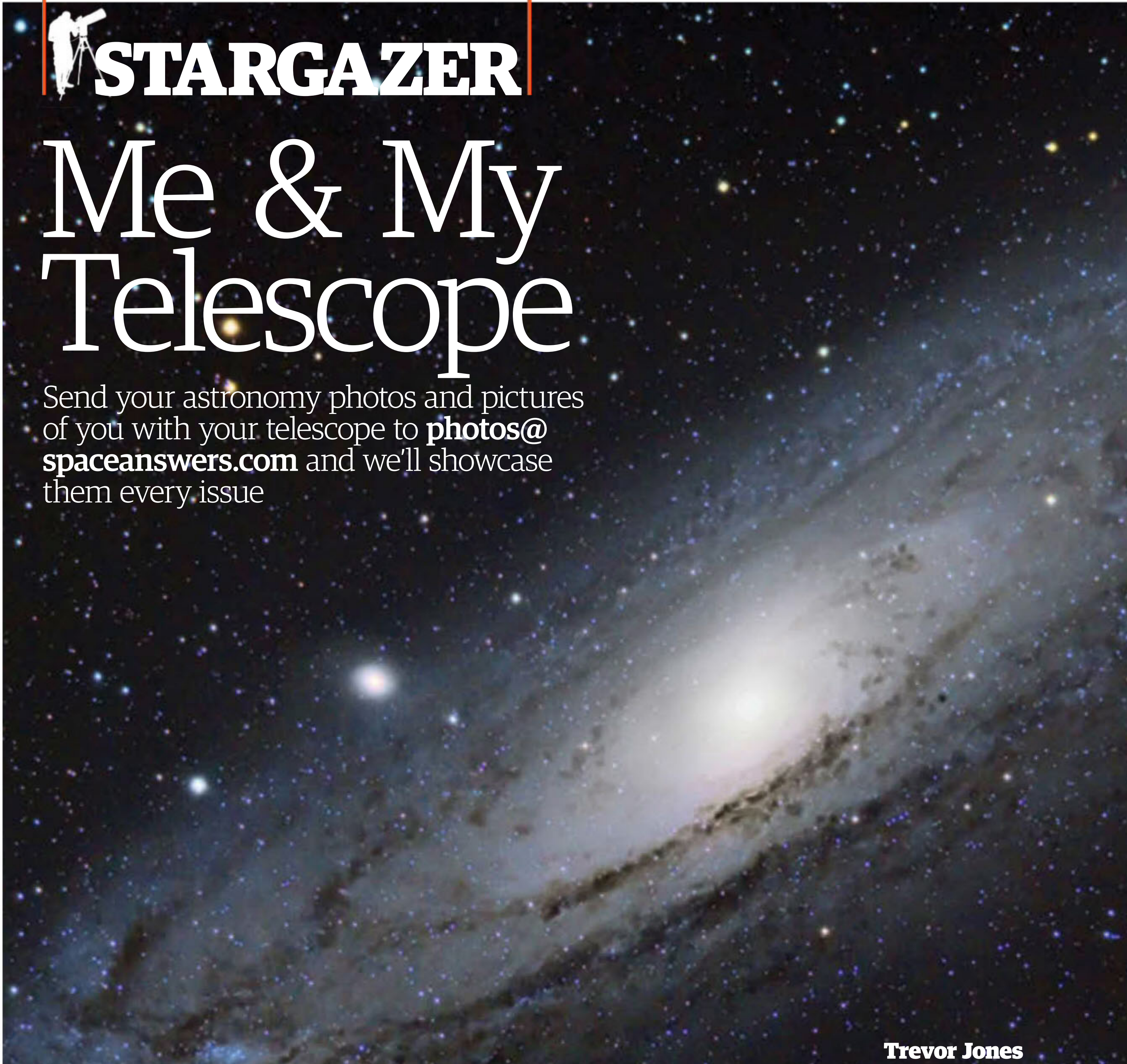
© NASA

The Double Cluster,
NGC 884 & 869

Pearl Cluster,
NGC 3766

Me & My Telescope

Send your astronomy photos and pictures of you with your telescope to **photos@spaceanswers.com** and we'll showcase them every issue



Andromeda Galaxy (M31)

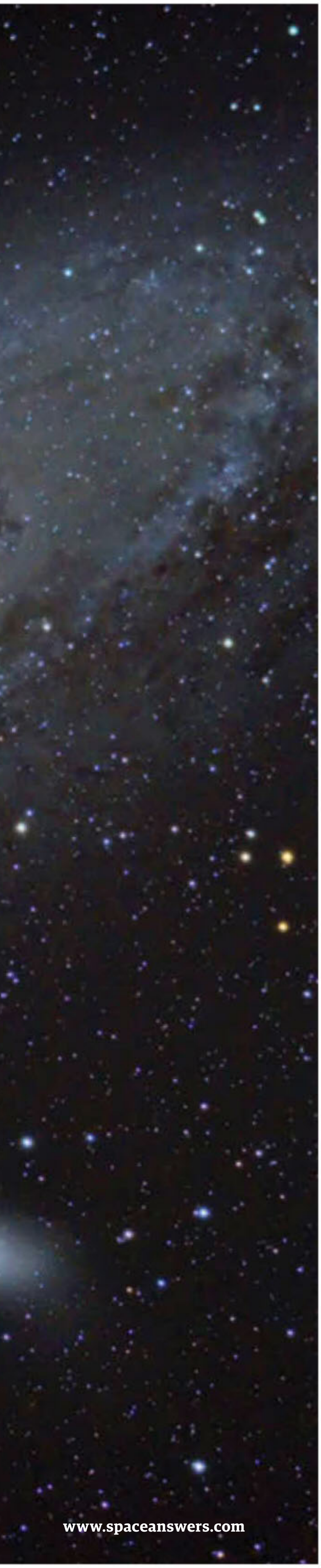
Trevor Jones

Ontario, Canada

Telescope: Explore Scientific ED80 refractor

"I have enjoyed many beautiful nights under the stars over the last four years. After joining the local astronomy club in my area, RASC Niagara, I learnt a lot about astrophotography in a short period of time. Whenever possible, I like to set up my telescope and take images of deep-sky objects to share on my astro-imaging blog.

"My shot of the Andromeda Galaxy, which is also designated Messier 31, is one of my favourite images to date. I took this image at the CCCA Observatory in Wellandport, Ontario, under exceptionally clear skies - it combines over three hours worth of four-minute exposures with a Canon 450D DSLR camera."

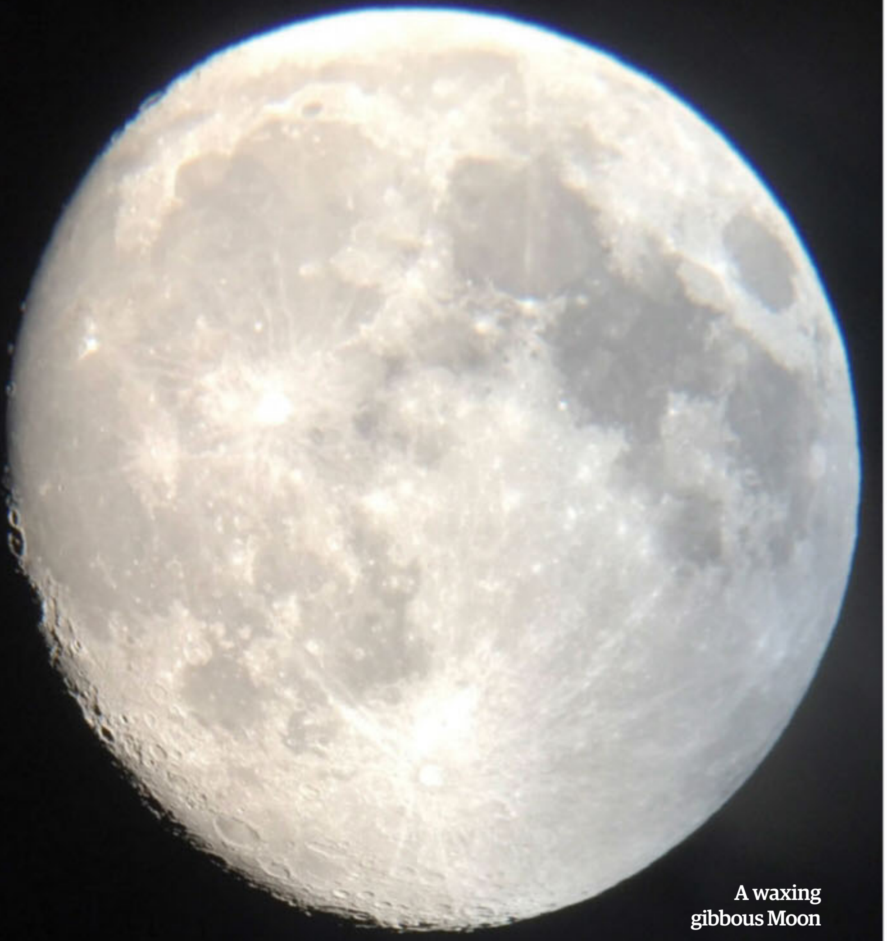


Sara Cesare

Napoli, Italy
Telescope: Sky-Watcher Skyliner 200P Dobsonian

"My passion for astronomy started when, at the age of 14, I began to study astronomy at school. I was so fascinated by black holes along with the idea of interstellar travel and wormholes that I was keen to learn more about this fascinating subject, which led me to buy many magazines about astronomy and, from that moment, I decided that I wanted to become a professional astrophysicist.

"I hope that my dreams will come true while I continue to watch deep space with the help of my Dobsonian telescope, which my parents bought for me after a trip to England."



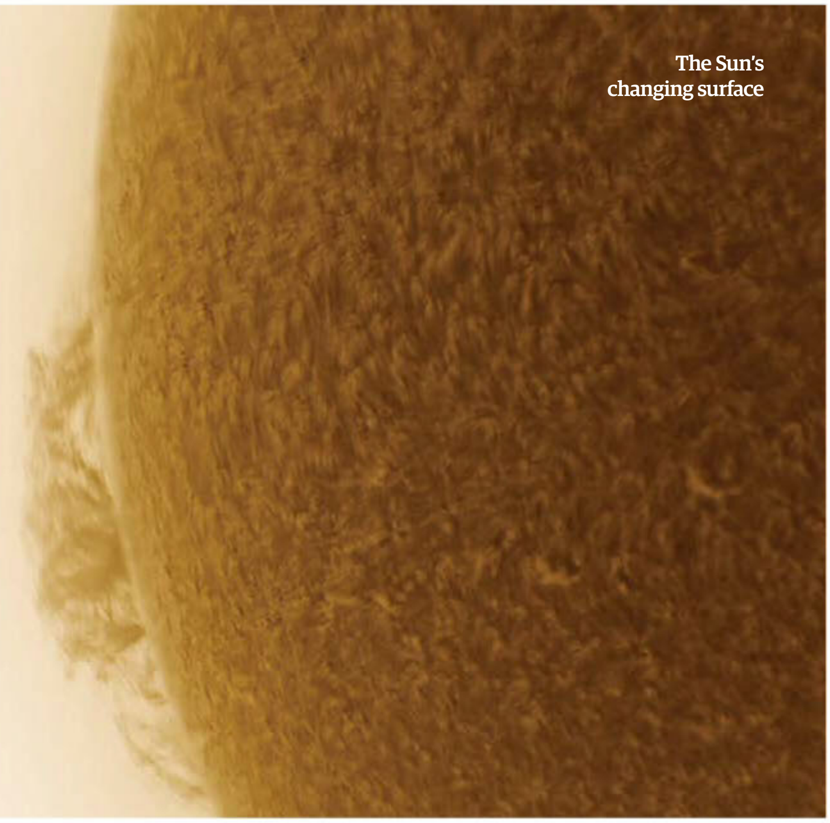
A waxing gibbous Moon

Stuart Hilliker

West Sussex, UK
Telescope: Coronado SolarMax 60 II

"After recently upgrading to the SolarMax 60 II from a Personal Solar Telescope (PST), I'm really impressed with the solar telescope's performance. It has certainly revealed much more surface detail on the Sun's surface than I could ever have managed with my earlier telescope.

"It's great to observe and image our nearest star. The constantly changing surface is full of surprises and it certainly makes a pleasant change to be able to observe and image in a warm and light environment rather than a freezing one, while trying to find a filter I've dropped in the darkness!"



The Sun's changing surface

Send your photos to... @spaceanswers photos@spaceanswers.com

Stargazing stories

Email the story of how you got into astronomy to **photos@spaceanswers.com** for a chance to feature in **All About Space**

Scott Phillips

Location: Llanelli, South Wales
Twitter: @scottphillips11
Info: Astronomer for one year
Current rig
Telescope: Sky-Watcher Skymax 127 GoTo
Mount: EQ-5 SynScan
Other: Canon 450D DSLR camera

"I've always been interested in space but I think I truly decided to get into astronomy after a six-month trip to New Zealand. After a spectacular sight of the Milky Way, with the whole sky filled with stars nearly every night, my mind was blown.

"When I returned to the United Kingdom, I started researching how I could get involved in stargazing and shortly after purchased my first telescope (Travel Scope 70). The first sight I got of the Moon still amazes me to this day and it's still my favourite object to image since it is so close and has an incredible amount of detail on its surface.

"Since then I have gone on to learn how to capture the amazing sights I have managed to view through my scope. It wasn't long until I got into astrophotography, which has led to my images being featured in a variety of astronomy magazines.

"My hobby in astronomy has caused me to start up a local astronomy society called Carmarthenshire Astronomy Club close to my home in Llanelli and we regularly meet up to share our interest in the night sky.

"I plan to upgrade my astronomy equipment over the next few years, especially the kit I use for astro-imaging since my DSLR camera isn't the best for photographing the planets in the Solar System, so I hope to get a CCD camera. A larger telescope would also come in handy!" ●

> "The first sight I got of the Moon amazes me to this day"

Scott's top three tips

1. Do your research

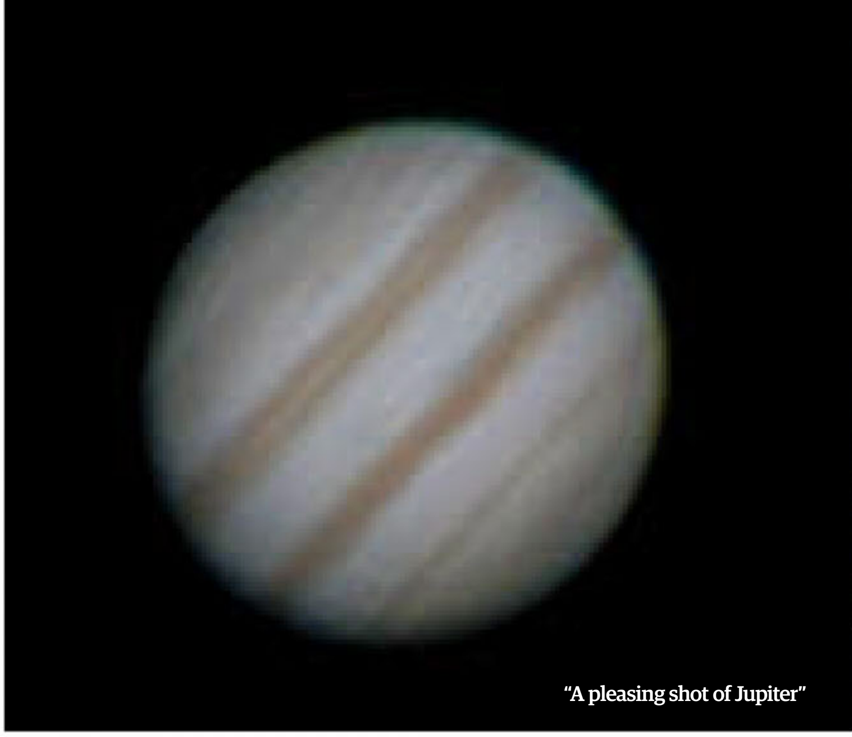
Don't go and buy a telescope without reading up on it first. It's important to find out if the instrument suits your needs and is easy to use.

2. Spend wisely

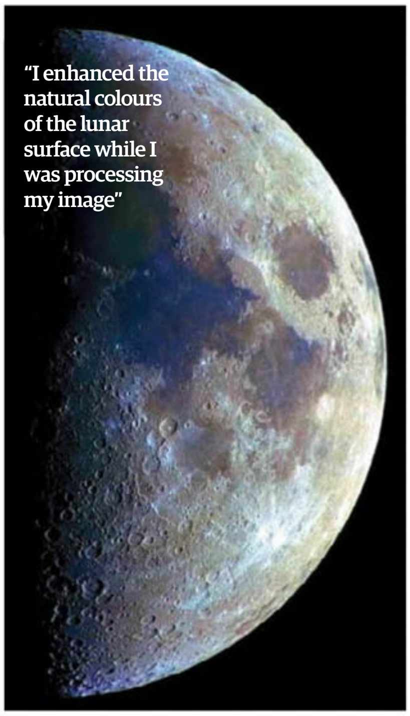
Don't buy high-end equipment right away – invest in either a good set of binoculars or a small to medium-sized manual scope.

3. Join a club

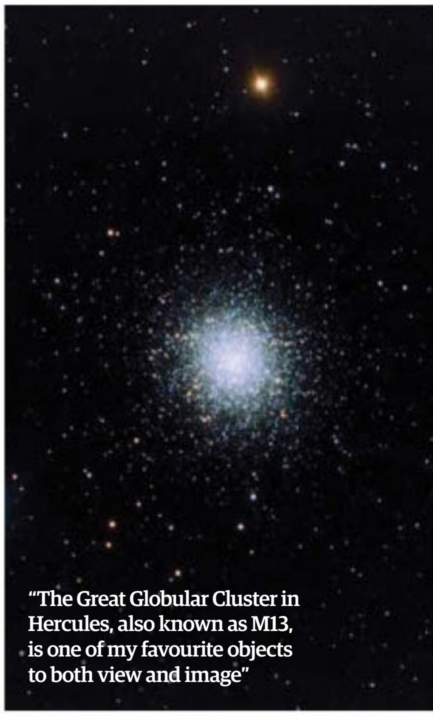
By joining a local astronomy club, you will have access to a deluge of information that will help you to get into stargazing on the right foot.



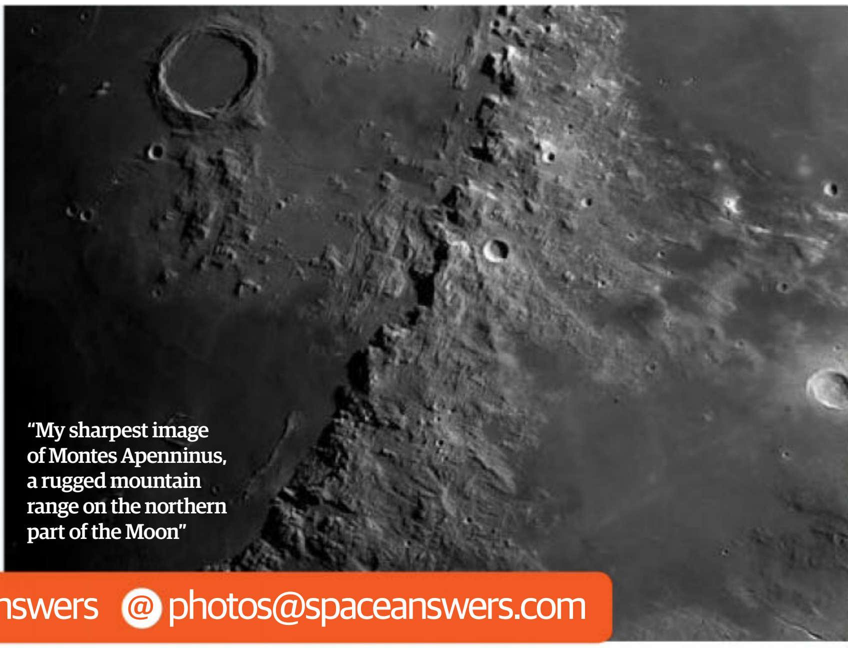
"A pleasing shot of Jupiter"



"I enhanced the natural colours of the lunar surface while I was processing my image"



"The Great Globular Cluster in Hercules, also known as M13, is one of my favourite objects to both view and image"



"My sharpest image of Montes Apenninus, a rugged mountain range on the northern part of the Moon"

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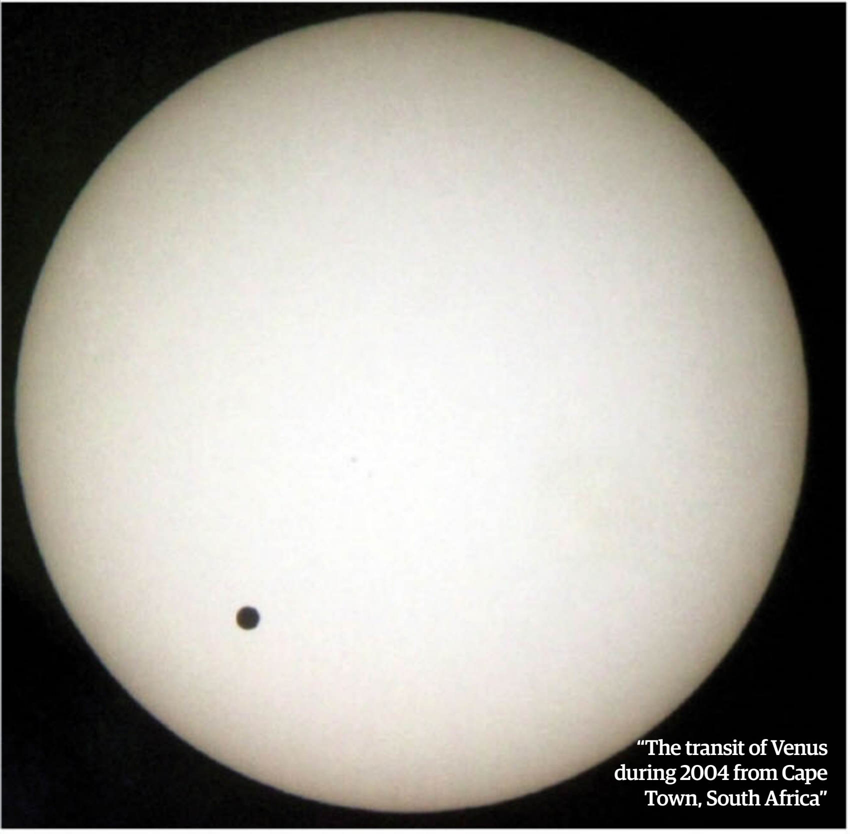
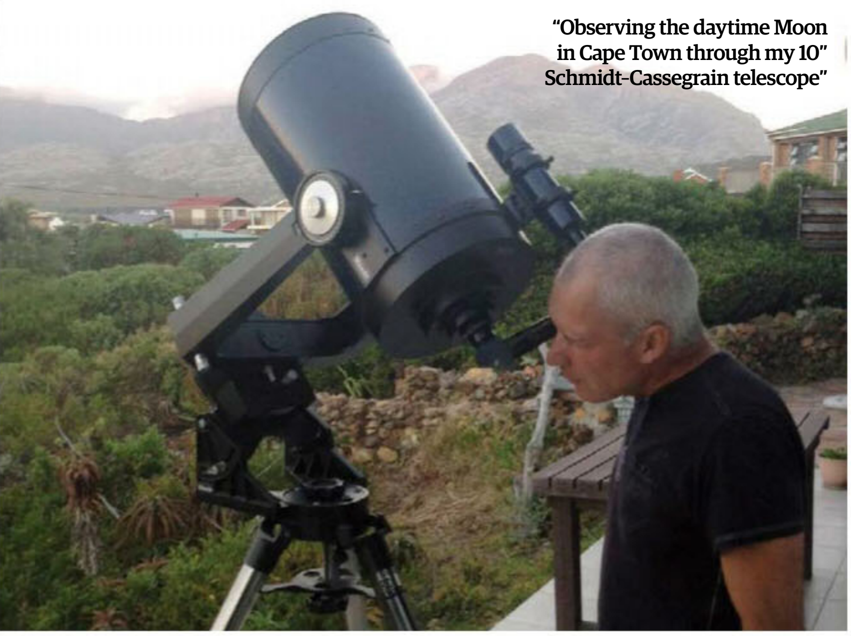
"Conjunction of Venus, the Moon and Jupiter in June this year"



"The transit of Venus during 2004 from Cape Town, South Africa"



"Observing the daytime Moon in Cape Town through my 10" Schmidt-Cassegrain telescope"

Frederik de Jager

Location: Cape Town, South Africa
Twitter: @novafred
Info: Astronomer for 40 years
Current rig
Telescope: 10" Meade LX90 GPS Schmidt-Cassegrain
Mount: Motorised equatorial
Other: Canon PowerShot G10 DSLR, iPad

"I began my hobby in astronomy attempting to build a telescope from my mother's reading glasses but ended up in more trouble than it was worth. Eventually, and during my first year of primary school, I resorted to painting all of the fences on our property during the holidays to save enough money to buy my first small three-inch refractor. It was this telescope that helped me to produce a hand-drawn map of the Moon, which later became my most prized possession.

"It was when Mars hit opposition and I wanted to get better views of its white polar cap that I thought seriously about getting a larger telescope. Ambitiously, I obtained a half-finished six-inch mirror from a friend and got to work building the telescope that would provide the exquisite views of the universe I was looking for. Polishing for weeks on end, the finished mirror was only capable of revealing the craters on the Moon and so I resorted to buying an eight-inch mirror to assist in building my own Dobsonian telescope.

"When it comes to observing, I particularly enjoy the dark skies above Cape Town in South Africa. A highlight of mine was viewing the dark spots caused by Comet Shoemaker-Levy 9 when it slammed into Jupiter in July 1994. I have also been lucky enough to see the transit of Venus across the Sun in 2004 and, later in 2007, I saw the spectacular Comet McNaught while Venus was emerging from behind the Moon. Recently, the stellar explosion Nova Sagittarii reached naked eye visibility and I also enjoyed the conjunction of Venus and Jupiter earlier this year." ●

"Comet McNaught (C/2006 P1) with Venus having just emerged from being occulted by the Moon in 2007"

Frederik's top three tips

1. Observe bright targets first

Go for targets that are easy to find and view with the naked eye – these include the Moon, a bright ISS pass or bright planets such as Jupiter and Venus.

2. Try out scopes

First plan a trip to a local astronomical society club or observatory open night where you can meet seasoned astronomers, ask questions and compare telescopes before buying.

3. Make use of apps

If you're struggling to find your way around the night sky with ease, apps available on smartphones and tablets are a great way to identify constellations, planets and other objects.

Visionary FirstView Table Top

Compact and easy to use, this small reflector is ideal for the entire family

Telescope advice

Cost: £49.99 (approx $80)
From: Optical Hardware Ltd
Type: Dobsonian
Aperture: 3"
Focal length: 11.8"

Best for...

- ? Beginners
- £ Low budgets
- Planetary viewing
- Lunar viewing
- Bright deep-sky objects

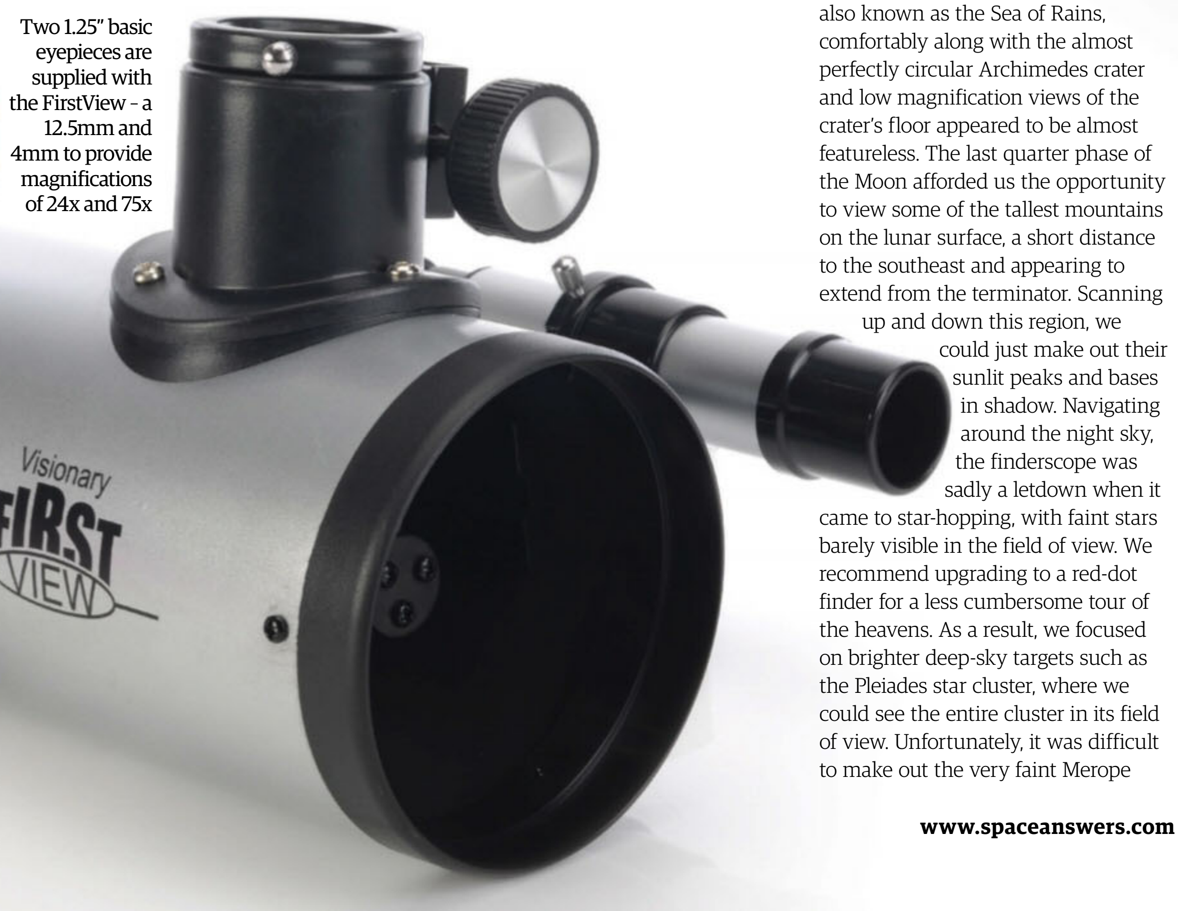
Given its 'toy-like' appearance, we didn't have high hopes for the Visionary FirstView. However, while the views through this desktop telescope wouldn't suffice for those taking a serious step into astronomy, it does the job for children who are keen to learn about space as well as parents who have taken a passing interest in viewing the universe. What's more, at just £49.99 it's not a huge outlay if the novelty of stargazing happens to wear off. The Visionary FirstView provides the experience of astronomy at a low price, allowing the user to test the waters before taking the plunge into a new hobby.

On unpacking the telescope, we were pleased to find that it already came preassembled and, as soon as you unbox it, it is ready to use. Combine this with its small size and you have a recipe for an instrument that promotes a fuss-free evening of observing. It is also easy to pack away, either by placing in a cupboard or on a windowsill as an ornament and takes up very little space. A cover for the main mirror also comes with the instrument to ensure that it is protected from dust when it is not in use. Two eyepieces are supplied - a 12.5mm and 4mm to provide magnifications of 24x and 75x, making it ideal for observing the brighter planets and the surface of the Moon. Unfortunately, the eye relief of these eyepieces is not particularly good, so those who wear spectacles may find themselves having to upgrade. Visionary has also generously supplied a Moon filter, making clear the enhanced observing experience that you can achieve with this additional piece of kit. The FirstView comes with everything to get started - including a finderscope to navigate the night sky. Weighing in at a light 1.8 kilograms (four pounds), the FirstView is also ideal for travelling should you wish to take it to a dark-sky site.

According to Visionary, the FirstView is able to capture 60 per cent more light than a typical 60mm beginner's telescope. Intrigued, we couldn't wait for a sufficiently clear evening to test this out. We made a near full Moon our first target but unfortunately all we managed to see was a blindingly white disc, washing out most of the features. Attaching the supplied Moon filter to the screw threads at the bottom of the eyepieces did assist with toning down some of the harshness, however, we decided to wait until a last quarter Moon to test out the FirstView's optics on the lunar surface.

When that evening rolled around, we weren't too disappointed with what the FirstView had to offer. Using the 4mm, which ensured that the lunar surface covered the field of view, the desktop telescope provided pleasing sights that are sure to delight children and first-time observers, however, while these views of the lunar surface are not pin-sharp, we were able to observe Mare Imbrium, also known as the Sea of Rains, comfortably along with the almost perfectly circular Archimedes crater and low magnification views of the crater's floor appeared to be almost featureless. The last quarter phase of the Moon afforded us the opportunity to view some of the tallest mountains on the lunar surface, a short distance to the southeast and appearing to extend from the terminator. Scanning up and down this region, we could just make out their sunlit peaks and bases in shadow. Navigating around the night sky, the finderscope was sadly a letdown when it came to star-hopping, with faint stars barely visible in the field of view. We recommend upgrading to a red-dot finder for a less cumbersome tour of the heavens. As a result, we focused on brighter deep-sky targets such as the Pleiades star cluster, where we could see the entire cluster in its field of view. Unfortunately, it was difficult to make out the very faint Merope

Two 1.25" basic eyepieces are supplied with the FirstView - a 12.5mm and 4mm to provide magnifications of 24x and 75x



The FirstView does look 'toy-like', however, it offers views that both children and entry-level astronomers will enjoy

The finderscope isn't ideal for star-hopping. A red-dot finder is much more effective

Thanks to its small size and Dobsonian design, the FirstView was already assembled when we unboxed it

“The FirstView allows you to test the waters before taking the plunge into astronomy”

Nebula, which can be seen embedded in the cluster, even with averted vision.

Keen to begin moving on to other Solar System targets, we waited until the early hours of the morning to locate Jupiter in the constellation of Leo in the pre-dawn sky in the east. Venus, which reprised its role as ‘the morning star’, wasn't difficult to miss as it shone at a brilliant magnitude of -4.5 to the right of Jupiter. Having such bright targets allowed us to test the FirstView's finderscope, which is quite difficult to use given its positioning against the main tube. However, for the telescope's price, the optical ability of the finderscope did the job with locating these bright targets. Displaying its greatest illuminated extent, only 25 per cent of Venus's surface is expected to be visible. We could just make out a ‘miniature waning crescent’ phase of the second planet from the Sun. Turning our attention to Jupiter before daylight washed it out from view, the king of the Solar System appeared as a bright disc, with its four largest moons - Ganymede, Io, Callisto and Europa - appearing as points of light either side of the planet.

For the price, you can't go wrong with the FirstView, especially if you have a youngster pestering you for a telescope or you're unsure if astronomy is the hobby for you. Alone, the telescope provides views that will please the entry-level astronomer and has scope to be improved for an even better viewing experience. ■

Planet Earth Education

Planet Earth Education
And Mobile Stars Planetarium

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How does Astronomy affect our everyday life?

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- **Constellations can be used for navigation.**
- **Astronomy is one of the oldest sciences.**

Planet Earth Education is one of the UK's most popular and longest serving providers of distance learning Astronomy courses. We pride ourselves on being accessible and flexible, offering attractively priced courses of the highest standards. Students may choose from five separate Astronomy courses, suitable for complete beginner through to GCSE and first-year university standard.

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WIN A MEADE POLARIS 130MD TELESCOPE

Kick-start your stargazing hobby with this month's competition

Courtesy of:
hama
The smart solution
MEADE

WORTH £250!

As part of our essential two-part guide to becoming an astronomer, we've teamed up with telescope manufacturer Meade and distributor Hama Products to offer you the chance to win a telescope kit, which comes complete with everything you need to begin touring the night sky.

With its five-inch aperture, the Meade Polaris 130 delivers exquisite views of a wide selection of night-sky objects – from Solar System targets to a variety of deep-sky objects such as the Andromeda Galaxy and the Orion Nebula. A stable German equatorial mount with slow controls enables easy tracking, allowing you to keep objects in your field of view as they move across the night sky, while a motor drive allows multi-speed tracking of the Moon, planets and stars. A stainless-steel tripod with an accessory tray – to hold the supplied 6.3mm (103x), 9mm (72x), 26mm (25x) three-element eyepieces and 2x Barlow Lens – provides the finishing touch to a sturdy and capable instrument.

A breeze to set up, this reflector offers good portability, offering you the versatility of transporting it the short distance to your back garden or further afield to your favourite dark-sky location. The supplied Autostar Suite planetarium software contains information on over 10,000 objects found in the heavens to ensure that you're free to tour the night sky – whatever the weather!

To be in with a chance of winning, all you have to do is answer this question:

What is the most Earth-like planet we have discovered so far?

A: Gliese 667 Cc

B: Kepler-438b

C: Kepler-442b

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Spotting scopes for casual astronomers

We pit two spotting scopes against each other to see which deserves a place in your stargazing armoury

Olivon T800 20-60x80mm

Cost: £349.99/$509
From: Optical Hardware Ltd

The Olivon T800 is a very well manufactured piece and features nitrogen fog-proofing inside the armour that keeps the optical system protected from water. This spotting scope is light enough to hold but, in order to achieve steady views of targets, a T-mount and tripod are an essential piece of kit. The objective lens cap was, at first, difficult to remove, but with a bit of twisting and turning we managed to get it off.

The Moon was our first target and, we have to say, the Olivon T800's optical system performed very well. The rugged lunar surface looks wonderful up close and in a definition that rivals a small refractor telescope. We did note colour-fringing at the edge of the Moon, which sadly spoiled the view. The same occurred when we observed Jupiter and its moons, with the gas giant's bright white disc tinged with blue. The Galilean moons did appear as points of light in the field of view and as expected for the spotting scope's optical ability.

The instrument comes with a 20-60x zoom eyepiece but thanks to a 1.25" eyepiece fitting, the Olivon T800 is a versatile piece of kit, allowing you to use a selection of astronomical eyepieces – this is something that many casual astronomers will be pleased with and is a feature that gives the Olivon T800 an edge over many spotting scopes.

Meade Wilderness 20-60x100mm

Cost: £345/$519.95
From: Hama Products

As soon as you take the Meade Wilderness out of the box, you'll notice the exceptional build. While we wouldn't expect anything less from manufacturer Meade, we felt confident that this scope will last for many observing sessions to come. Wrapped up snuggly in rubber armour to protect the main body and optics from abrasions that come about from regular use, this spotting scope is also waterproof, meaning that you don't have to worry too much about the dew that often plagues telescopes and binoculars. The instrument is also very easy to use with the 20-60x zoom eyepiece complementing the optical system extremely well.

During an exceptionally cold night, the Meade Wilderness's promise of a fog-free observing session was well and truly met. We enjoyed clear views of a waxing gibbous Moon and made our way along the terminator for astonishing views of the craters and lunar mare. The four-inch objective lens along with the 20-60x zoom eyepiece collected enough light to make Jupiter and its moons an enjoyable sight. Sadly though, we did notice colour-fringing around some of the brighter night-sky targets. On the other hand, though, the anti-reflection coating on the optics ensured otherwise exquisite views.

While pleasant to hold, for steady views the Meade Wilderness does require a tripod and T-mount, which are unfortunately not supplied. What's more, if you're someone who likes to dabble in wildlife watching as well as a fair amount of night-sky viewing, the Meade Wilderness fits the bill nicely.

Verdict

Winner: Meade Wilderness 20-60x100mm

While the Olivon T800 is a decent instrument, the Meade Wilderness is our preferred spotting scope for casual astronomy. Not only do you get a larger aperture for a lower price, but the build well and truly surpassed that of the harder casing that surrounds the optical system of the T800. While both instruments are plagued by colour-fringing, the Meade Wilderness provided superior views of the Moon and naked-eye planets over its competitor.

Astronomy kit reviews

Stargazing gear, accessories, games and books for astronomers and space fans alike

1 Compass

Celestron TrekGuide

Cost: £35 / $34.95

From: David Hinds Ltd

The Celestron TrekGuide is a four-in-one digital compass, barometer, altimeter and thermometer that worked well overall, however, we couldn't rely on it for land navigation through a dark sky site and the altimeter is not very consistent. After holding the TrekGuide's thermometer in our hand for a period of time we noted that the measurement was off by a few degrees compared to other thermometers in the area. Letting the device adjust to the surrounding air, however, seemed to rectify the problem. On the other hand, the weather forecast feature seemed to work fairly well. A bright green light, which serves as a backlight, allowed us to comfortably see the display but it did ruin our night vision.

For assisting with stargazing, the Celestron TrekGuide isn't our cup of tea. Beyond providing a rough weather forecast estimate, it didn't add much more to our observing experience. ■

2 Book

Nature Guide Stars and Planets (DK Nature Guide)

Cost: £9.99 / $14.95

From: Waterstones

A good proportion of this book can be found in *The Practical Astronomer*, also published by DK. However, this guide costs less and the constellation charts are larger and easier to use.

If you're looking to learn the constellations and want to discover some new targets, then this is a good starting point. Each constellation has a dedicated page, meaning that you can take your time focusing on a one-star pattern and its treasures over the course of an evening. Full sky maps are also supplied for each month. The star maps didn't wash out under red light, which is a massive positive.

Unfortunately, not all nebulae, galaxies and star clusters are listed in the observing sections, meaning that it is limited to those who have just started out in astronomy. As with all Dorling Kindersley products, each and every page is beautifully illustrated. ■

3 Globe

Insight Globe: Stargazer

Cost: £9.99 (approx $15)

From: Waterstones

Charming and small enough to keep on your desk without causing an obstruction, this stargazer globe is an immediate hit in the **All About Space** office. With all of the finer details of each of our planet's 88 constellations and finished in a bright eye-catching shade, it has an impressive amount of stunning detail.

However, due to its small size some may need a magnifying glass to see some of the less conspicuous constellations, such as Lyra. For this reason, this globe serves best as an ornament rather than an aid to navigate the night sky.

If you're a fan of the night sky, or know someone who is, then we can't recommend this globe enough. While it can't be used as an observing aid, you can certainly gain familiarity with the constellations and most famous stars in the night sky – whichever hemisphere of the world you're in. ■

4 App

PhotoPills (v 1.2.7)

Cost: £7.99 / $9.99

From: iTunes

Sadly, unless you have an iOS device, you won't be able to experience what PhotoPills has to offer. It assists with planning a shoot, making the most of your camera and also allows you to collaborate with others on imaging.

Planning is everything when it comes to getting the perfect shot. We loved the feature that allows you to get the date and time for when the Moon, stars or Milky Way will be in a specific part of the sky, wherever you are in the world. Augmented reality meant that we were able to get a very good nightscape shot of the Milky Way, thanks to PhotoPill's ability to pinpoint the position of our galaxy's major stars.

PhotoPills accounts for the elevation of obstacles and also assists with factors such as depth of field to give you an idea of how your image will look. It is compatible with a variety of cameras such as the Canon XC10 and the Panasonic Lumix DMC-G7. ■

Grunsfeld completed a total of eight spacewalks during his five Space Shuttle flights

John Grunsfeld

The valiant journeys of Hubble's keeper

Born in Chicago, Illinois, in 1958 to the renowned architect Earnest Alton Grunsfeld III, John Grunsfeld's youth was filled by the drama and excitement of the Space Race. As an adventurous and idealistic young man, he frequently daydreamed in class, doodling pictures of mountains and spaceships in the margins of his school books. Even in his early years, Grunsfeld had a passion and drive to explore everything the Earth, and beyond, had to offer.

This desire for adventure led Grunsfeld to participate in a number of wilderness courses in his teenage years where he built up the essential leadership skills that would aid him in his later life. In 1980, he graduated from the Massachusetts Institute of Technology where he achieved a degree in physics. This was soon followed by a doctorate in physics from the University of Chicago. In his spare time Grunsfeld enjoyed mountaineering, but there was a very important place he still wished to explore - space.

In 1992, Grunsfeld got a little closer to that dream when he was selected by NASA to become an astronaut. Determined to achieve his goal, he worked hard and trained until his first mission launched in March 1995. Aboard Space Shuttle Endeavour as a mission specialist, this 16-day mission saw Grunsfeld and his crew conduct a number of observations to study the far ultraviolet spectra of astronomical objects. To do this they used the Astro-2 Observatory, a system of telescopes that was on board the Shuttle.

Grunsfeld's leadership skills impressed NASA and he served as flight engineer on his second flight, which was aboard Atlantis in January 1997. This was the fifth flight that docked with Mir, the Russian station where US astronauts were exchanged. They also transferred supplies and conducted a number of experiments in the laboratory. In December 1999, Grunsfeld returned to space on-board Discovery on a mission to service the Hubble Space Telescope. He performed two EVAs to install new equipment on the telescope and restore it to working order.

Grunsfeld was back in space on-board Columbia when it launched in 2002 for another Hubble-servicing mission, except this time he served as payload commander. This made him responsible for five EVAs, three of which he performed himself. Yet again Grunsfeld's work helped to expand the capabilities of the telescope and ensure it was in top working order. In 2009, he conducted his last flight on Atlantis, where he helped to renovate and install a new camera, telescope, sensor and batteries in Hubble after its 19 years in orbit.

By this point Grunsfeld had made his name as the lead spacewalker for Hubble maintenance activities. During his five Space Shuttle flights he completed a total of eight spacewalks, racking up over 58 hours of EVA time and more than 58 days in space. For the little boy that had dreamed of exploring the universe, his mission was well and truly successful. Grunsfeld retired from NASA in 2009 and became the deputy director of the Space Telescope Science Institute, and also took up a position as a professor of physics and astronomy at Johns Hopkins University.

Although a lot of Grunsfeld's time was taken up by his work, he continued to pursue his love for mountaineering, becoming the only astronaut to reach the summit of Mount McKinley. He was also able to combine his love for climbing and science by helping with research concerning the effect of high altitudes on the body.

However, Grunsfeld couldn't stay away from NASA for long, and in 2012 he was appointed associate administrator for the Science Mission Directorate at NASA's headquarters. Eager to spread his love of space and science, Grunsfeld has conducted a number of lectures, interviews and television appearances to share his wisdom and experiences, as well as commenting on the latest advances in space exploration. ●

All About Space

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